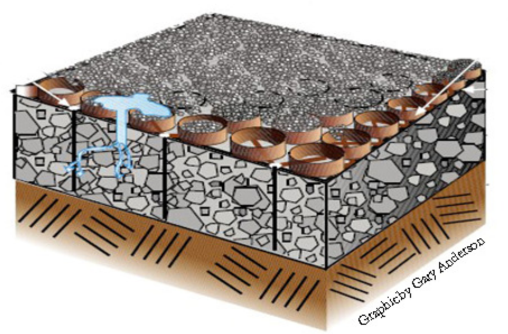
Low Impact Development

Guidance Manual for Site Design and Implementation

Principles of LID

- Conserve natural resources that provide valuable natural functions associated with controlling and filtering stormwater.
- Minimize and disconnect impervious functions.
- Use distributed small-scale controls or Integrated Management Practices (IMPs) to mimic the site's pre-project hydrology.
- Direct runoff to natural and landscaped areas conducive to infiltration.



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Low Impact Development

Guidance Manual for Site Design and Implementation

City of Flagstaff Utilities Division

Stormwater Management Section

211 West Aspen Avenue

Flagstaff, Arizona 86001

928-779-7650

PREFACE

Acknowledgements

While this document was prepared by Staff of the City of Flagstaff, this document was primarily adapted from The County of San Diego's *Low Impact Development Handbook, Stormwater Management Strategies* and The Urban Drainage and Flood Control District's (UDFCD, Denver CO.) *Urban Storm Drainage Criteria Manual, Volume 3 – Integrated management practices*. Chapter 2 of this Manual, *Site Planning Practices*, and Chapter 4, *Other Best Management Practice Factsheets*, are from The County of San Diego's LID Handbook. Chapter 3, *Engineered IMP's* and Chapter 5, *Maintenance Recommendations* were primarily adapted from the UDFCD's *Urban Storm Drainage Criteria Manual, Volume 3*. Unless otherwise noted, the figures and illustrations came from these respective sources.

The City would also like to acknowledge the invaluable assistance provided by the members of the Stormwater Advisory Committee (SWAC). We are grateful for the committee's time commitment and all of the comments, multiple revisions, and suggestions provided by the SWAC in preparation of this document.

General Intent

The intent of this *Manual* is to provide information on minimum acceptable design, construction, and maintenance practices for the use of Low Impact Development projects in the City of Flagstaff. However, it is recognized that the unique circumstances of a particular project may require innovative, unusual design and/or construction practices. It is therefore not the intent of the City of Flagstaff to prohibit the use of alternate materials, methods, or designs for Low Impact Development projects.

In all cases, two factors must be strongly stressed. First, good engineering practice is essential. (No attempt has been made in this *Manual* to set up complete design criteria.) Second, local site conditions must be evaluated in connection with any design.

Disclaimer

The City of Flagstaff does not endorse any of the commercial brands and products mentioned in this *Manual* and merely use them to illustrate the availability of potential sources of materials that meet the characteristics for designs recommended herein. The designer is encouraged to always consider the use of other products or brands that will provide equivalent or better level of performance or service.

The drawings contained in the *Manual* are intended to show design concepts. Preparation of final design plans, addressing details of structural adequacy, public safety, hydraulic functionality, maintainability, and aesthetics, remain the sole responsibility of the designer.

As with any release of publications and details, it is likely that some nonconformities, defects, and errors associated with this *Manual* will be discovered. The City of Flagstaff, Stormwater Section welcomes and encourages user feedback in helping to identify them so that improvements can be made to future releases of the *Manual* and other products.

CITY OF FLAGSTAFF LOW IMPACT DEVELOPMENT MANUAL

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1. INTRODUCTION

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1.1. PURPOSE

The Goal of the City of Flagstaff's Low Impact Development (LID) Program is to mitigate the effects of downstream impacts due to increased stormwater runoff from new development and to protect water quality. The strategy is to preserve and mimic nature through the use of stormwater planning and management techniques on project sites.

The LID Manual is designed to assist engineers, planners, developers, architects, landscape professionals, and others with engineering solutions and site planning practices that attempt to mimic natural hydrologic functions for development sites, and to use as guidance prior to developing a project site. This manual does not cover every existing stormwater Integrated Management Practice (IMP) and exclusion of other IMPs is not meant to preclude consideration of their use.

This manual also does not cover every aspect of the civil engineering and structural design necessary for proper IMP system design and construction, nor does it cover every site situation that may occur, nor every possible stormwater solution. The design professional is responsible for the design and construction of a properly functioning stormwater IMP that meets all of the applicable regulations and that considers all the unique conditions of an individual site. Where the designer determines that an alternative design may be more appropriate, alternative designs, materials, and methodologies will be considered on a case-by-case basis.

1.2. CONVENTIONAL STORMWATER MANAGEMENT

For over 50 years urban development and storm drain system design have consisted of streets, driveways, sidewalks and structures constructed out of impervious materials that directly convey runoff to curb and gutter systems, storm drain inlets and a network of underground storm drain pipes. They have been designed to convey stormwater away from developed areas as quickly and efficiently as possible[1]. Conventional storm drainage systems can include detention basins designed to reduce peak flows. However, they typically do not address stormwater quality or improvement of groundwater recharge.

When natural vegetated pervious ground cover is converted to impervious surfaces such as paved highways, streets, rooftops, and parking lots, the natural absorption and infiltration abilities of the land are lost. This typically results in post-development runoff with greater volume, velocity, and peak flow rate than pre-development runoff from the same area[2]. Runoff durations can also increase as a result of flood control and other efforts to control peak flow rates.

Increased volume, velocity, rate, and duration of runoff accelerate the erosion of downstream natural channels. Some of the impacts on downstream natural channels are:

Stream Hydrology: Urban development affects the environment through changes in the size and frequency of storm runoff events, changes in base flows of the stream and changes in stream flow velocities during storms resulting in a decrease in travel time for runoff. Peak discharges in a stream can increase from urbanization due to decrease in infiltration of rainfall into the ground, loss of buffering vegetation and resultant reduced evapotranspiration. This results in more surface runoff and larger loads of various constituents found in stormwater.

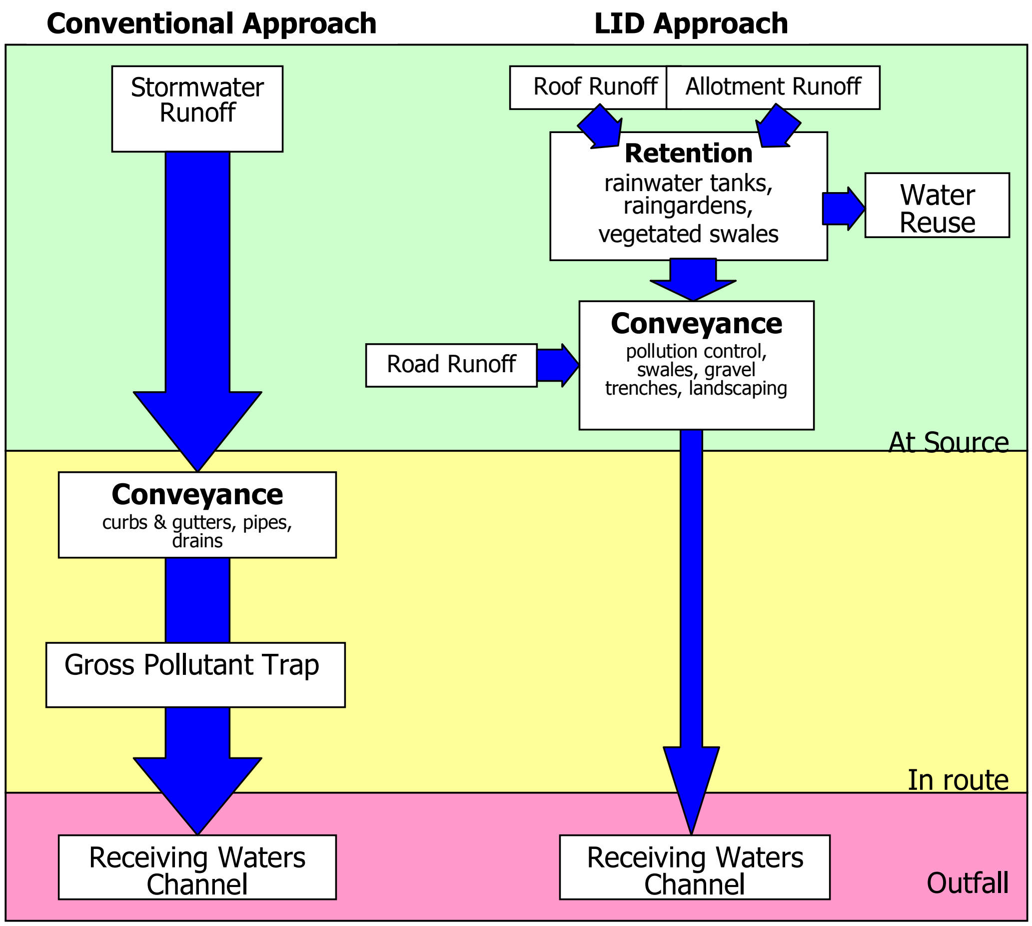
Stream Morphology: When the hydrology of the stream changes, it results in changes to the physical characteristics of the stream. Such changes include streambed degradation, stream widening, and streambank erosion. As the stream profile degrades and the stream tries to widen to accommodate higher flows, channel bank erosion increases along with increases in sediment loads. These changes in the streambed also result in change to the habitat of aquatic life.

Stream Quality: Water quality is impacted through urbanization as a result of erosion during construction, changes in stream morphology, and washing off of accumulated deposits on the urban landscape. Water quality problems include turbid water, nutrient enrichment, bacterial contamination, and increases in organic matter loads, metals, salts, oil/grease, pesticides and herbicides. In addition, there may be temperature increases and increased trash and debris transported by stormwater runoff to streams and lakes.

Around the Country conventional development has resulted in increased runoff rates, volume, and increased flooding potential. Urban development creates new pollution sources as human population density increases and brings with it proportionately higher levels of vehicle emissions and maintenance waste, municipal sewage, pesticides, household hazardous waste, pet waste, trash, etc. which is either washed or directly dumped into the storm drains. Individually, residential homes and businesses typically contribute relatively small amounts of runoff and pollutants. However, numerous studies have shown that the collective discharge of untreated runoff from large areas of conventional residential, commercial, industrial, and municipal development often results in significant environmental impacts to local water resources[3].

The volume and rate of runoff and the potential to transport pollutants to local water bodies depends on a variety of factors, including developed and proposed land use and management practices, and existing climatic, hydrologic and geologic conditions within a drainage area. Studies have shown that small storms, which occur more frequently than relatively large storms, typically transport the greatest load of pollutants downstream[4]. In addition, the majority of pollutants are typically transported during the "first flush" portion of a runoff event, which is often considered to be the first inch of a storm event. Therefore, the sizing of structural treatment controls and LID practices is most efficient and cost effective when they are designed to capture and treat the most frequently occurring storm events as well as the "first flush" portion of runoff producing storm events.

Conventional development and storm drain system design typically inhibit natural hydrologic functions by creating large impermeable surfaces that prevent infiltration and groundwater recharge, increase runoff, and discharge polluted runoff offsite. In addition to providing water quality benefits, LID practices reduce the quantity of runoff from developed areas and can assist with water conservation. Figure 1 compares conventional and LID stormwater management design approaches.



(Source: San Diego Low Impact Development Handbook)

Figure 1.1 Conventional vs. LID Stormwater Approach

1.3. Overview of LID

Low Impact Development is an innovative stormwater management approach with a basic principle that is modeled after nature: manage rainfall runoff at the source using decentralized small-scale controls uniformly distributed throughout the project area. It was pioneered in Prince Georges County, Maryland and has been applied successfully across the Country. LID's goal is to mimic a site's predevelopment hydrology by using design practices and techniques that effectively capture, filter, store, evaporate, detain and infiltrate runoff close to its source[5]. This can be accomplished by creating site design features that direct runoff to vegetated areas containing permeable/amended soils, protect native vegetation and open space, and reduce the amount of hard surfaces and compaction of soil.

LID practices are based on the premise that stormwater management should not be seen as merely stormwater disposal. Rather than conveying the runoff from small frequent storm events directly into underground pipes and drainage systems for discharge offsite, LID Integrated management practices (IMP) dissipate and infiltrate stormwater runoff with landscape features and, where practical, permeable surfaces located onsite, thereby reducing runoff volumes and filtering runoff before it leaves the site. Most forms of development have the ability to incorporate some level of LID design techniques and practices. However higher density infill and vertical development is more limited in feasible LID solutions whereas low-density residential development has more flexibility to incorporate LID design techniques.

LID design techniques and practices need to look at the major development features of a project, including project green space areas and landscaping, rooftops, streetscapes, parking lots, sidewalks, and medians. LID is a versatile approach that can be applied to new development, urban retrofits, redevelopment, and revitalization projects[4].

The Principles of LID can be characterized by the following five elements[6]:

Principles of LID

- Conserve natural resources that provide valuable natural functions associated with controlling and filtering stormwater
- Minimize & disconnect impervious surfaces
- Direct runoff to natural and landscaped areas conducive to infiltration
- Use distributed small-scale controls or Integrated Management Practices (IMPs) to mimic the site's pre-project hydrology
- Stormwater education leads to pollution prevention

LID is a stormwater management and design strategy that is integrated into design of the development project. LID complements other urban planning techniques such as "Smart Growth" "Green Building" and "Sustainable Development" by focusing on alternative approaches to stormwater runoff management and treatment. Smart Growth and Sustainable Development are land use planning terms that describe the efforts of communities across the Country to manage and direct growth in a way that reduces damage to the environment and builds livable towns and cities.

A sustainable community preserves and enhances the quality of life of residents both within and between communities, while minimizing local impact on the natural environment. Green or sustainable building is the practice of creating healthier and more resource-efficient models of construction, renovation, operation, maintenance, and demolition. The Principles of LID can be incorporated into Smart Growth, Green Building and Sustainable Development practices. LID does not replace local land use planning; rather, it is a complementary set of planning tools applied at the project level to better manage stormwater in areas appropriately designated for growth.

1.4. GOALS OF LID

LID's approach to urban planning and design aims to minimize the hydrological impacts of urban development on the surrounding environment. Both conventional stormwater management and LID are directed at providing flood control, flow management, and water quality improvements. In addition, LID recognizes that opportunities for urban design, landscape architecture and stormwater management infrastructure are intrinsically linked and is an element of whole system design.

The goal of LID site design is to reduce the generation of stormwater runoff and to treat pollutant loads where they are generated. This is accomplished with appropriate site planning and by directing stormwater towards small-scale systems that are dispersed throughout the site with the purpose of managing water in an evenly distributed manner. These distributed systems have the advantage of allowing for downsizing or elimination of stormwater ponds, curbs, and gutters. Because LID embraces a variety of useful techniques for controlling runoff, designs can be customized according to local management requirements and site constraints. Designers and developers can select the LID technologies that are appropriate to the site's topographic and climatic conditions that are appropriate to meet stormwater control requirements and specific project constraints and opportunities. New projects, redevelopment projects, and capital improvement projects are all candidates for implementation of LID[7].

Goals of LID

Protect Water Quality

Reduce Runoff

Reduce Impervious Surfaces

Encourage Open Space

Protect Significant Vegetation

Reduce Land Disturbance

Decrease Infrastructure Costs

1.5. BENEFITS OF LID

LID has numerous benefits and advantages over the conventional approach. LID is a more environmentally sound technology. By addressing runoff close to the source through intelligent site design, LID can enhance the local environment and protect public health. LID protects environmental assets, protects water quality, and builds community livability. Other benefits include[8]:

Benefits of LID

- Protects surface and ground water resources
- Reduces non-point source pollution
- Reduces habitat degradation
- Applicable to greenfield, brownfields, and urban developments
- Multiple benefits beyond stormwater (aesthetics, quality-of-life, air quality, water conservation and reuse, property values)
- Groundwater recharge (where needed)

As new development occurs over time, increased impervious area will result, affecting hydrologic functions such as infiltration, groundwater recharge, and the frequency and volume of discharges. These natural functions can be maintained with the use of LID practices, which reduce impervious surfaces, functional grading, open channel sections, disconnection of hydrologic flowpaths, and the use of bioretention/filtration landscape areas. In addition, cost savings are often realized through reduced material costs, site paving, and grading and preparation.[9]

In areas where groundwater recharge is desired, LID is beneficial because these practices facilitate rainwater infiltration. Rainwater infiltration is needed for adequate groundwater recharge, especially to provide adequate recharge to endure extended drought periods. Groundwater recharge directly influences local water tables. Increased impervious area can reduce rainfall infiltration, which can lead to increased risk of potential impacts from drought.

1.6. LIMITATIONS OF LID

Not all sites can effectively utilize all of the LID techniques and it is the responsibility of the designer to determine which techniques are appropriate. Soil permeability, soil contamination, and slope, may limit the potential for local infiltration. Urban areas planned for multifamily and mixed use development or high rise construction and locations with existing high contaminant levels in the soil may be severely limited or precluded from using LID infiltration techniques onsite. A more community-level approach to LID rather than a site by site approach may be warranted. Other non-infiltration LID techniques such as street trees, permeable pavements with an under drain, raised sidewalks, rain water harvesting with appropriately designed barrels or cisterns, vegetated roofs/modules/walls are still an option for projects in the urban setting, however these techniques must be carefully integrated into projects.

1.7. REFERENCES

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2. SITE PLANNING PRACTICES

Contents

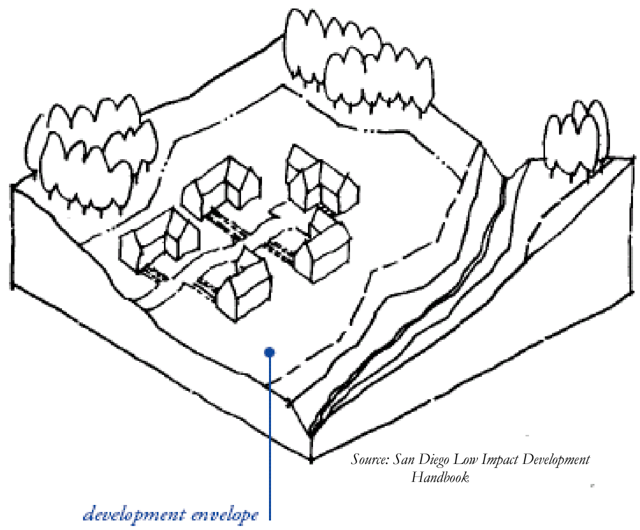
2.1. INTRODUCTION

The first step in applying LID principles is to assess the site for existing environment and land use constraints should include evaluation of existing conditions such as hydrology, topography, soils, vegetation, and drainage features to identify how stormwater moves through the site prior to development. These can be combined to delineate the best areas for development to occur on the site. Permeable soils, or soils offering the best available infiltration potential, should also be noted and utilized. Building sites, road layout, and stormwater infrastructures should be configured within these development areas to reduce soil, significant vegetation, and drainage disturbance and take advantage of a site's natural stormwater processing capabilities.

The following sections outline strategies that can be incorporated into the site planning process. The end result will be a developed site that will not only minimize the quantity and improve the quality of stormwater runoff, but also offer aesthetic landscaping, visual breaks that increase a sense of privacy within a variety of housing densities, and design elements that promotes neighborhood identity.

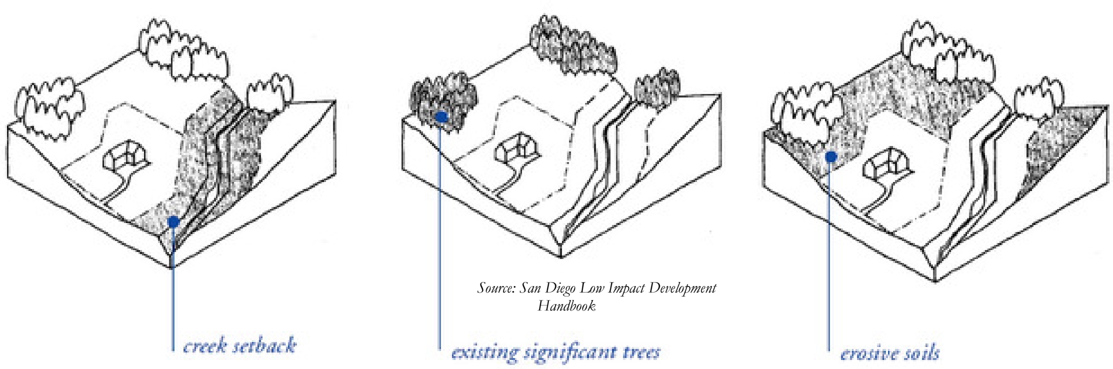
2.2. CONSERVE NATURAL AREAS

The first site planning strategy is to conserve natural resources on site. Assess the site for significant trees, shrubs, sensitive vegetation, and permeable soils and consider easements, setbacks, etc., to define the development envelope and create the draft plan. In the case of redevelopment, if existing plants are of the high water use type, consider replacing with lower water use plants.



Source: San Diego Low Impact Development Handbook

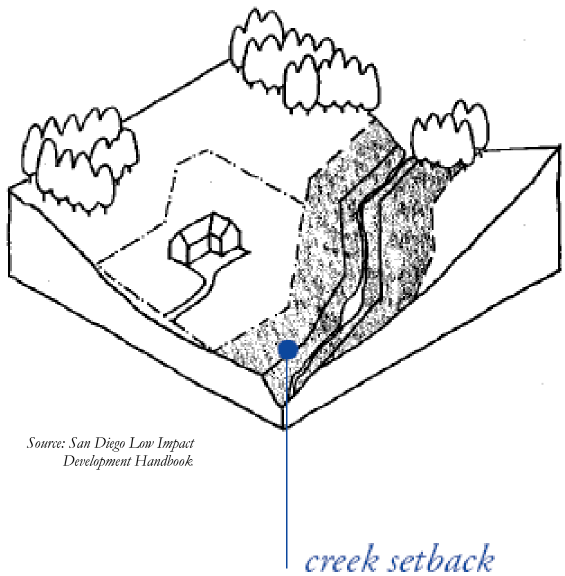
The upper soil layers of a natural area contain organic material, soil biota, vegetation, and a configuration favorable for storing and slowly conveying stormwater. The canopy of existing native trees and shrubs also provide a water conservation benefit by intercepting rain water before it hits the ground. By minimizing disturbances in these areas natural processes are able to intercept stormwater, providing a water quality benefit. By keeping the development envelope concentrated to the least environmentally sensitive areas of the site and set back from natural areas, stormwater runoff is reduced, water quality can be improved, environmental impacts can be decreased, and many of the site's most attractive native landscape features can be retained. Retaining these natural landscape features will count toward landscaping, resource, and slope protection per the City of Flagstaff Land Development Code (LDC). In some situations, site constraints, regulations, economics, and/or other factors may not allow avoidance of all sensitive areas on a project site.



Source: San Diego Low Impact Development Handbook

2.3. MINIMIZE DISTURBANCES TO NATURAL DRAINAGES

The next site planning strategy is to minimize impacts to natural drainages (natural swales, topographic depressions, etc.). Natural drainages offer a benefit to stormwater management as the soils and habitat already function as a natural filtering/infiltrating swale. Restoring a degraded natural drainage (as in the case of redevelopment) will also result in these benefits. When determining the development footprint of the site, natural drainages should be avoided. By keeping the development envelope set back from natural drainages, the drainage can retain its water quality benefit to the watershed. Implementing "treatment train" IMPs, such as filter strips and bioretention, further protect the natural swale from runoff and help to increase the site's stormwater benefit by reducing stormwater runoff, improving water quality, decreasing environmental impacts, retaining sensitive habitat areas and attractive landscape features.



Source: San Diego Low Impact Development Handbook

2.4. MINIMIZE AND DISCONNECT IMPERVIOUS SURFACES

To reduce runoff peaks and volumes from urbanizing areas, it is recommended that a practice generally termed "minimizing directly connected impervious areas" (MDCIA) be employed. The principal behind MDCIA is twofold -- to reduce impervious areas and to route runoff from impervious surfaces over grassy or rock areas to slow down runoff and promote infiltration. The benefits are less runoff, less stormwater pollution, and less cost for drainage infrastructure.

2.4.1. Approach to Minimizing Directly Connected Impervious Areas (MDCIA)

There are several approaches to reduce the imperviousness of a development site:

Reduced Pavement Area: Although the City's LDC dictates the allowable street cross sections, when possible; the use of smaller roadway cross sections and smaller paved parking lots is encouraged. Sometimes, creative site layout can reduce the extent of paved areas, thereby saving on initial capital cost of pavement and then saving on pavement maintenance, repair, and replacement over time.

Porous Pavement: The use of porous pavement or reinforced turf can significantly reduce site imperviousness. This practice can reduce the extent and size of the downstream storm sewers and detention.

Vegetated Buffers: Draining impervious areas over vegetated buffers slows down runoff and encourages infiltration, in effect reducing the impact of the impervious area.

Vegetated /Rock Swales: The use of vegetated or rock swales instead of storm sewers, like vegetated buffers, slows down runoff and promotes infiltration, also reducing effective imperviousness. It also can reduce the size and cost of downstream storm sewers and detention.

Green Roofs: One additional practice that may be worth considering in commercial and industrial developments and some residential buildings is the use of green roofs. Under Flagstaff's climate green roofs may need supplemented irrigation. There are a number of green roof systems on the market and this Manual makes no attempt to distinguish between them.

2.4.2. Benefits of Reducing Imperviousness

- Reducing imperviousness offers the following benefits:
- Increased infiltration and decreased rate and volume of site runoff
- Decreased runoff and, in turn decreased size of required infiltration facilities
- Decreased peak runoff rates and volumes for downstream conveyance and detention facilities
- Reduced need for irrigation
- Less curb and gutter
- Smaller storm sewer systems
- Decreased pavement areas
- Decreased runoff rates and volumes further downstream in watershed, especially if MDCIA is used on a widespread basis

2.4.3. Integrated Management Practices (IMPs) for Minimizing Effective Imperviousness

Described next are structural IMPs that minimize effective imperviousness.

Vegetated buffer (VB)

Uniformly graded and dense area of native vegetation. This IMP requires sheet flow to promote filtration, infiltration, and settling to reduce runoff pollutants.

Vegetated /Rock Swales (GS)

Densely vegetated drainageway with low-pitched side slopes that collects and slowly conveys runoff. Design of shallow longitudinal slope and cross-section size forces the flow to be slow and shallow, thereby facilitating sedimentation while limiting erosion.

(Rock Swale at NAU campus entrance)

Porous Pavement (PP)

Porous pavement consists of a porous pavement layer that is underlain by gravel and sand layers in most cases. This IMP is intended to be used in parking lots and in low traffic areas to accommodate vehicles while facilitating stormwater infiltration near its source.

(Gravelpave parking lot at Grand Canyon Trust)

2.4.4. Applying Minimizing Directly Connected Impervious Areas (MDCIA) to a Site

Minimizing directly connected impervious areas requires a basic change in land development design philosophy. This change seeks to reduce paved areas, use porous pavement and direct stormwater runoff to landscaped areas, vegetated buffer strips, and vegetated/rock swales to slow down the rate of runoff, reduce runoff volumes, attenuate peak flows, and encourage filtering and infiltration of stormwater. Traditional land development practices have not focused on water quality enhancement. Instead, they promoted runoff from rooftops, parking lots, driveways, and roads to quickly flow to a curb and gutter and to a formalized stormwater conveyance system. This approach to drainage concentrates runoff quickly, which results in a fast responding system, increased runoff volumes, and relatively large peak runoff rates during small storms.

Minimizing directly connected impervious areas can be made an integral part of landscape and drainage planning for any development. Roofs can be of the green roof type, drainage from rooftop collection systems can direct flow to landscaped areas, infiltration areas such as porous landscape detention and porous pavement, vegetated buffer strips, and to vegetated/rock swales.

Instead of using solid curbing, eliminate curbing or use slotted curbing along with stabilized native vegetation shoulders and swales. Residential driveways can be porous pavement or the runoff from them can be redirected from flowing directly into the street. Large parking lots can reduce DCIAs by using porous pavement to encourage local infiltration or storage.

Site slopes should be capable of directing stormwater runoff by gravity in a sheet flow away from buildings, roads, and parking lots toward native vegetation-covered or porous pavement covered areas. The runoff then needs to flow as a sheet over these porous surfaces before it reaches swales, storage, stormwater collection, and stormwater conveyance systems. As a result, in areas of high permeability soils (Hydrologic Soil Class A and B soils), the ground can provide for infiltration of large portions of surface runoff. Where less permeable soils (Hydrologic Soil Class C and D soils) are present, significant runoff losses can also be achieved, while the use of sand trenches with underdrains under vegetated/rock swales can be used to reduce the nuisance of standing water.

Steep sites with average terrain slopes exceeding 4 to 5 percent may not lend themselves well to implementing some aspects of some of these IMPs. Some of the difficulties can be dealt with by using terracing and retaining walls. Nevertheless, most sites with general terrain slopes flatter than 4 to 5 percent should be suitable for this family of IMPs.

2.4.5. Application Examples

The following figures provide a number of illustrations of how the principle of MDCIA can be applied to development sites. Figure 2.1 shows an example of MDCIA for a residential and commercial site. Figure 2.2 shows an example for a multi-family residential site and Figure 2.3 shows typical application examples of modular block porous pavement.

The Total Percent of Watershed Imperviousness for the traditional residential layout in Figure 2.1is approximately 47%. Using porous pavement and a native vegetation swale, as shown at the bottom of the figure, reduces the Total Percent of Watershed Imperviousness to 34%. This shows that the inclusion of IMPs can significantly reduce total imperviousness.

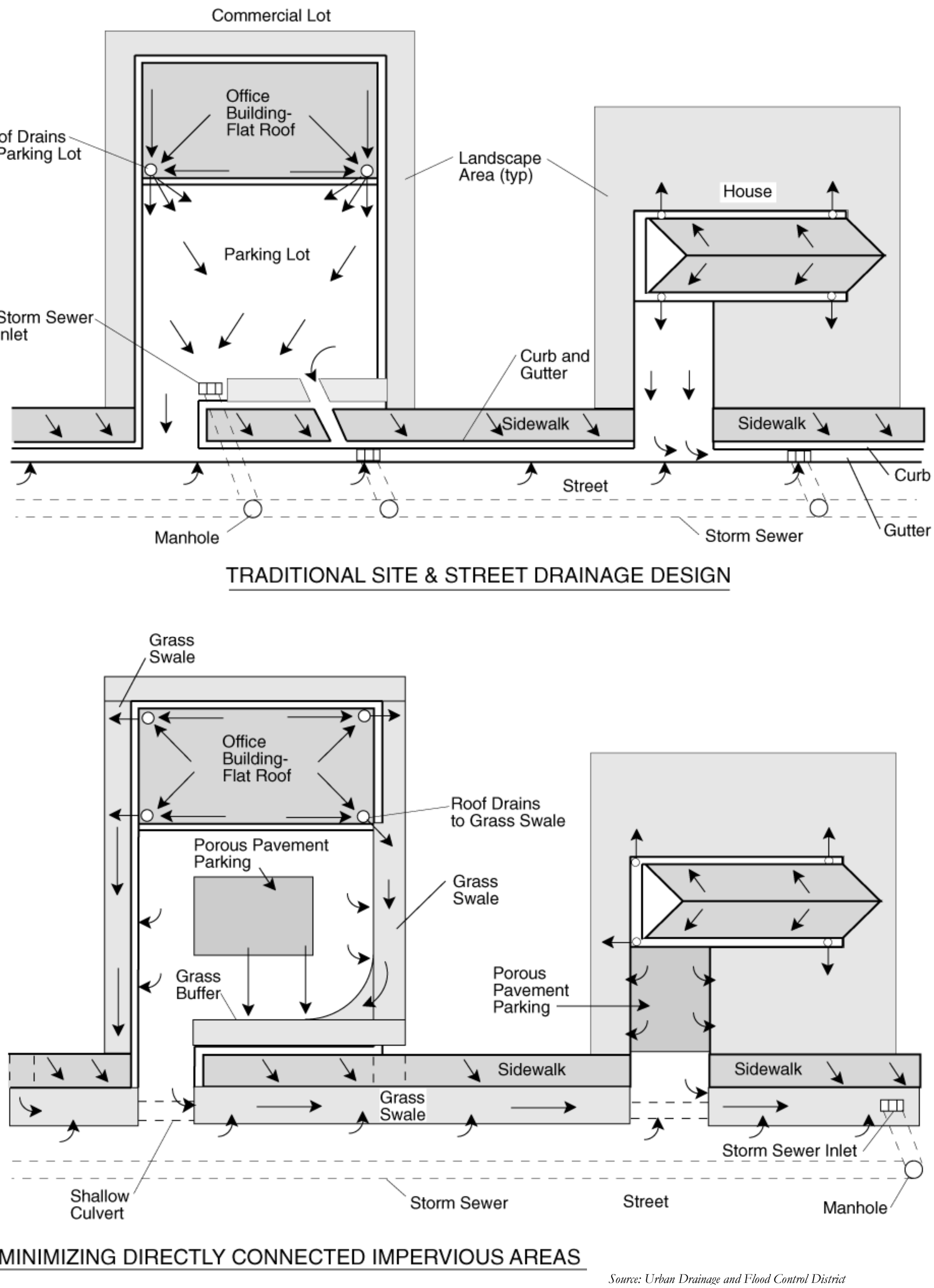


Figure 2.1 - Example of Minimized Directly Connected Impervious Areas–Residential and Commercial

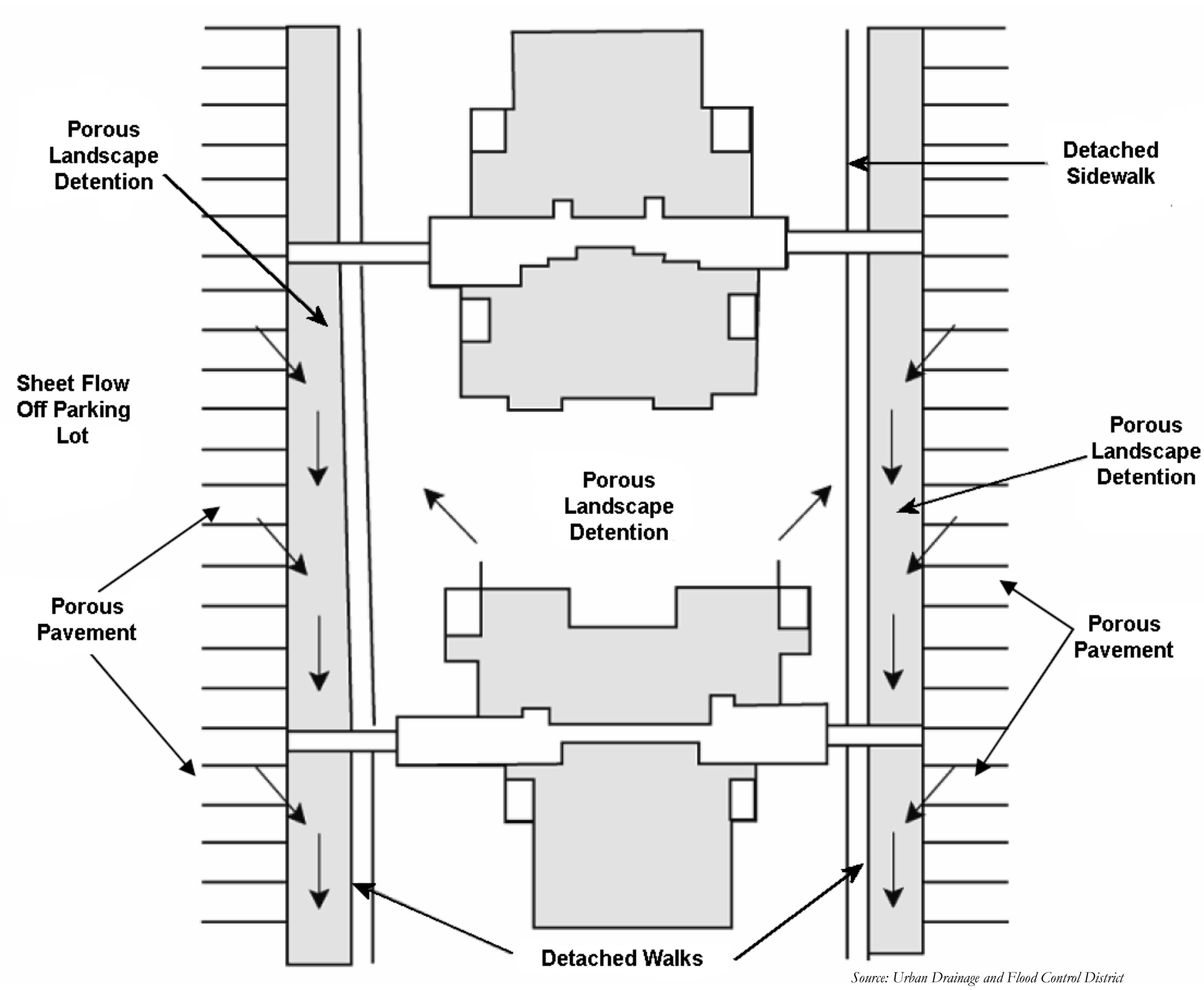


Figure 2.2 - Examples of MDCIA for a Multi-Family Residential Development
(Porous Landscape Detention also refers to Bio-Retention)

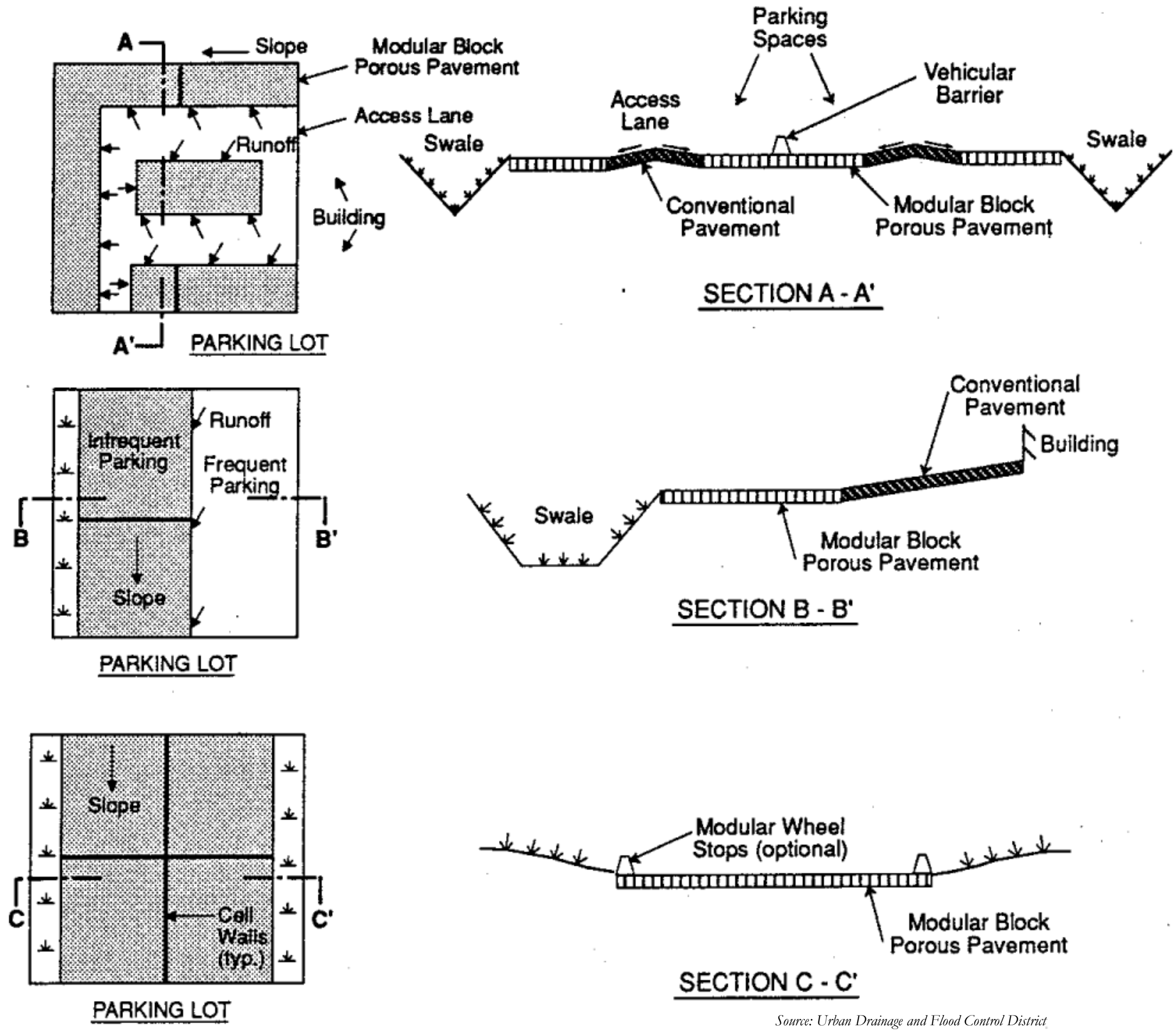


Figure 2.3 - Typical Applications of Modular Block and Porous Pavement

2.5. MINIMIZE SOIL COMPACTION

Another planning strategy is to minimize soil compaction in planned pervious areas (infiltration areas, landscaping, lawns, green space etc.) and reduce the overall area of soil disturbance. The upper soil layers contain organic material, soil biota, and a configuration favorable for storing and slowly conducting stormwater down gradient. By protecting native soils and vegetation in appropriate areas during the clearing and grading phase of development the site can retain some of its existing beneficial hydrologic function. It is important to recognize that areas adjacent to and under building foundations, roads and manufactured slopes must be compacted with minimum soil density in compliance with geotechnical requirements and building codes.

Clearing and grading exposes and compacts the underlying subsoil, producing a site with significantly different hydrologic characteristics. For this reason, disturbance should be avoided in planned green space and proposed landscaped areas where feasible. These areas that are planned for retaining their beneficial hydrological function should be restricted during the grading/construction phase so that vehicles and construction equipment do not intrude and inadvertently compact the area. Protecting native soil and vegetation to retain the beneficial hydrologic function during the clearing and grading phase can present a significant yet important challenge within the development process.

In urban sites, it may not be possible to avoid soil disturbance. In areas planned for landscaping where compaction could not be avoided, re-tilling of the soil surface should be performed to allow for better infiltration capacity. Soil amendments are recommended and may be necessary to increase permeability and organic content. Soil stability, density requirements, and other geotechnical considerations associated with soil compaction must be reviewed by a qualified, licensed geotechnical, civil or other professional engineer.

2.6. PROVIDE RUNOFF CAPTURE VOLUME

As required by the City of Flagstaff Stormwater Management Manual, the first one inch of runoff from all impervious surfaces will be infiltrated or reused on-site. This quantity of runoff is known as the *runoff capture volume (ROCV).* One or more of four types of water quality facilities, each draining slowly to provide for long-term settling of sediment particles, may be selected.

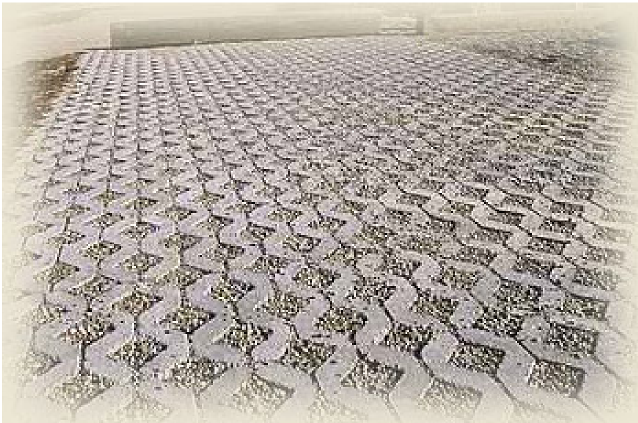
2.6.1. Benefits of ROCV Facilities

These IMPs are designed to capture and provide treatment for the ROCV. Detention volume drain times range from 6- to 36-hours, depending on the type of facility. The primary pollutant removal mechanism consists of physical settling of suspended sediments and associated adsorbed pollutants. Secondary pollutant removal mechanisms include filtering, biological uptake, and adsorption. In addition to water treatment, facilities with a *ROCV* mitigate to some extent the effects of hydrologic changes that take place when lands urbanize.

The *ROCV* treatment facilities recommended in this *Manual* were chosen because they have demonstrated proven results in semi-arid areas, are relatively cost-effective and are necessary at any development or redevelopment site. Runoff from 100-percent of the impervious surfaces of a site must flow through a properly designed installation of one or more of the *ROCV* IMPs that are listed herein. Alternate designs may be considered, but they must have equivalent functional requirements of these IMPs, including *ROCV* and its drain times.

2.7. TYPES OF *ROCV* FACILITIES

A brief description of the four types of *ROCV* facilities follows.



Picture from OmniPro Pittsburgh

Porous Pavement Detention (PPD)

Porous pavement detention consists of modular block porous pavement that is installed flat and is provided with a 2 inch deep detention zone above its surface to temporarily store the *ROCV* from the tributary drainage area including its own surface. Runoff infiltrates into the void spaces of the gravel Base Course through the sand filter and slowly exits through an underdrain.

Auto Dealership at the Automall

Bio-Retention Cell

A bio-retention cell consists of a low lying vegetated area underlain by a gravel storage bed with an underdrain. A shallow surcharge zone exists above the cell for temporary storage of the *ROCV*. This IMP allows small amounts of *ROCV* to be provided on parking lots or adjacent to buildings without requiring the set aside of significant developable land areas.

East Flagstaff Detention Basin

Extended Detention Basin (EDB)

An extended detention basin is appropriate for larger sites and is designed to totally empty out sometime after stormwater runoff ends. The extended detention basin uses a much smaller outlet than a flood control detention basin, which extends the emptying time for the more frequently occurring runoff events to facilitate pollutant removal.

Willowbend Enivronemntal Center

Water Harvesting/reuse

Harvesting the ROCV for reuse, either outdoor or indoor, is a sustainable approach to meeting the ROCV requirement while providing an alternative water source. This is a practical option in our semi-arid climate as the City population increases and the effects of extended drought are felt.

2.7.1. Application Examples for Porous Pavement and Bio-Retention

Porous pavement and Bio-Retention provide an opportunity to incorporate *ROCV* into a new land development site or a redevelopment site while minimizing the impact on developable area. Just as the principle of MDCIA requires a change in drainage philosophy, so does the application of porous pavement and Bio-Retention. These IMPs need to be applied on a relatively small scale and are ideally suited to small sites or individual small sub-catchment areas of large sites. They can also be used in conjunction with standard detention basins.

The following figures provide a number of illustrations of how porous pavement and Bio-Retention can be applied in a development site. Figure 2.4 and Figure 2.5 show examples for a multi-family residential site, and Figure 2.6 shows an example for a commercial site parking lot.

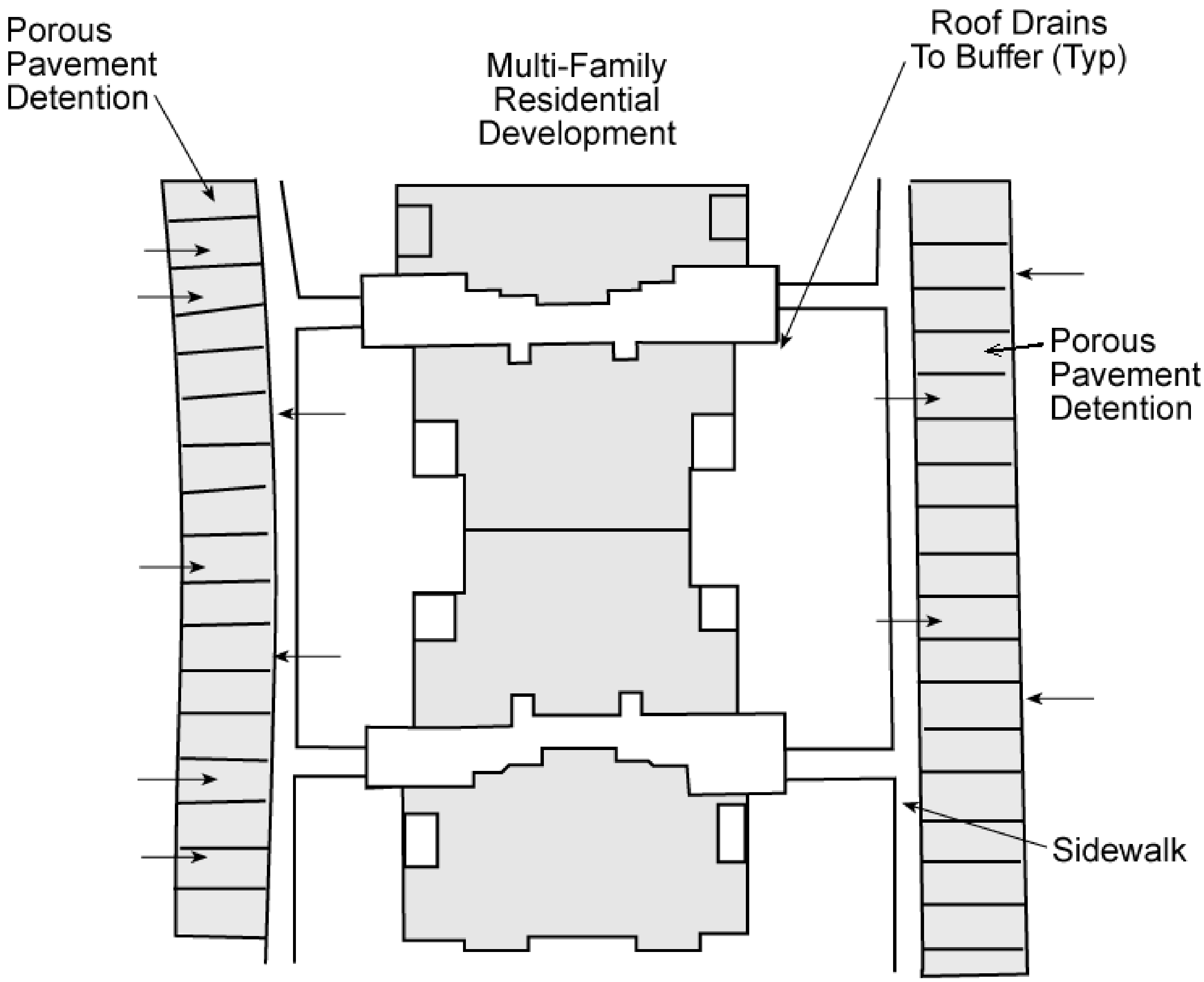


Figure 2.4 - Examples of Porous Pavement Detention for a Multi-Family Residential Development

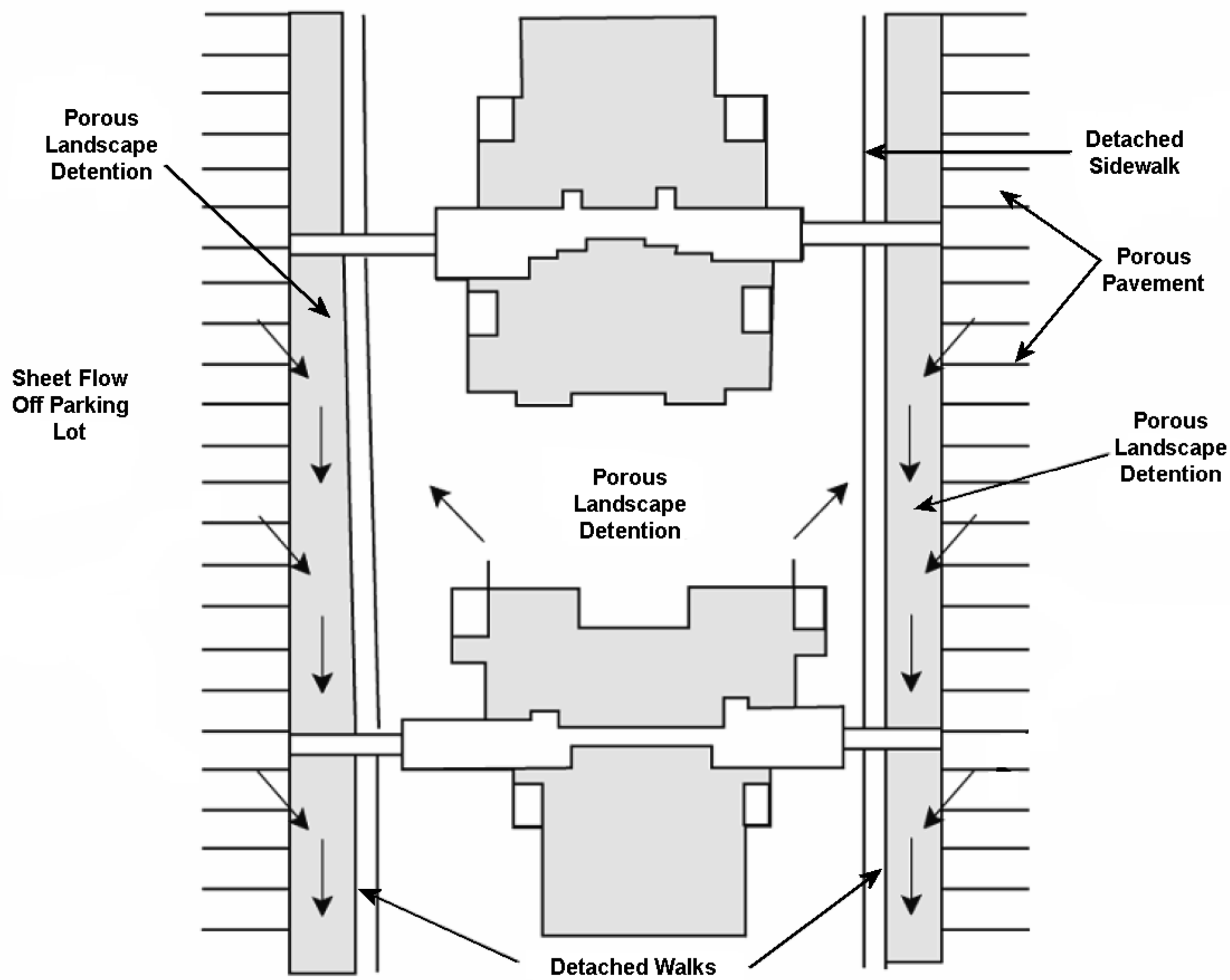
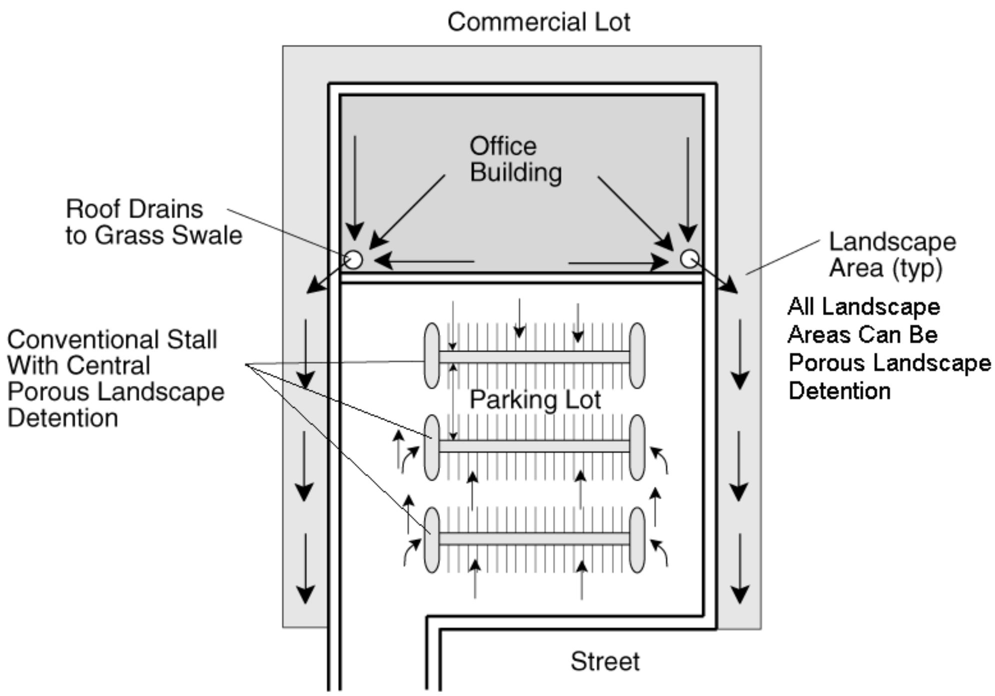


Figure 2.5 - Examples of Bio-Retention for a Multi-Family Residential Development ***(Porous Landscape Detention also refers to Bio-Retention)***



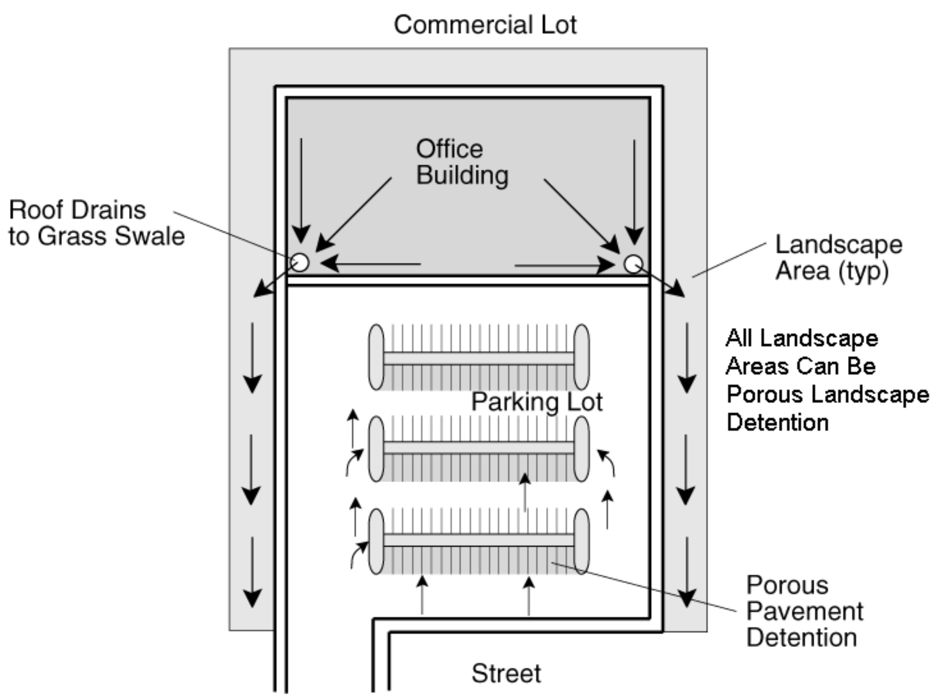


Figure 2.6 - Examples of Porous Pavement and Bio-Retention for a Commercial Development (Parking Lot)
(Porous Landscape Detention also refers to Bio-Retention)

2.7.2. Guidance for Selecting and Locating ROCV Facilities

Porous pavements and Bio-Retention facilities are generally suited for small drainage areas (i.e. typically less than 1.0 acre); however, larger subwatersheds can be subdivided into individual drainage sub-catchment areas meeting this limitation.

Laying out *ROCV* facilities within a development site and watershed requires thought and planning. One of the questions involved in laying out *ROCV* facilities on a site is whether to locate a IMP on-stream or off-stream. Onstream refers to locating a IMP on a drainageway that traverses a site such that all of the runoff from the upstream watershed flows through the facility. A single onstream IMP can treat both site runoff and runoff generated in any upstream offsite catchment areas that are part of that watershed. Locating IMPs offstream requires that all onsite catchment areas flow though a IMP prior to entering the drainageway. Offstream IMPs do not provide treatment of runoff from any upstream drainage catchment areas.

2.7.3. Incorporating *ROCV* into Stormwater Detention Basins

The *ROCV* facility can be incorporated into stormwater detention basins. When combined, the 10, and 100-year detention levels are provided above the *ROCV* and the outlet structure is designed to control two different releases.

3. ENGINEERED INTEGRATED MANAGEMENT PRACTICES

Contents

3.1. INTRODUCTION

This section provides a description and detailed design information for structural Integrated Management Practices (IMPs) that promote filtration, infiltration, and settling to reduce the volume of runoff and concentration of pollutants. This section was adapted primarily from the Structural Best Management Practices chapter of the *Urban Storm Drainage Criteria Manua*l, Vol 3. by the Urban Drainage and Flood Control District in Denver Colorado.

All LID "infiltration IMPs" proposed for a specific project shall be reviewed and approved for use in the project by the project's geotechnical engineer, civil engineer, or other qualified licensed professional to avoid the potential for slope failure, water seepage or migration under structures or on to neighboring property, conflicts with underground utilities, or other potential conflicts with engineering and design objectives.

3.2. LIST OF ABBREVIATIONS

BR	Bio Retention
EDB	Extended detention basin
MBP	Modular block porous pavement
MBP	Modular Block Pavers
MDCIA	Minimizing directly connected impervious areas
PCP	Porous Concrete Pavement
PICP	Permeable Interlocking Concrete Pavers
PP	Porous Pavement
PPD	Porous pavement detention
RGP	Reinforced Grass Pavement
ROCV	Runoff capture volume
RPGP	Reinforced Porous Gravel Pavement
VB	Vegetated buffer
VRS	Vegetated/rock swale

3.3. VEGETATED BUFFER STRIP

3.3.1. Description

Vegetated buffer (VB) strips are an integral part of the MDCIA land development concept. They are uniformly graded and are planted with native and low water use vegetation. They require sheet flow to promote filtration, infiltration and settling to reduce runoff pollutants. VBs differ from vegetated/rock swales as they are designed to accommodate overland sheet flow rather than concentrated or channelized flow. They can be used to remove larger sediment from runoff off impervious areas.

Whenever concentrated runoff occurs, it should be evenly distributed across the width of the buffer via a flow spreader. This may be a porous pavement strip or another type of structure to achieve uniform sheet-flow conditions. VBs can also be combined with riparian zones in treating sheet flows and in stabilizing channel banks adjacent to major drainageways and receiving waters. VBs can be interspersed with shrubs and trees to improve their aesthetics and to provide shading. Although use of native and drought tolerant plants will minimize irrigation requirements, it may still be required to maintain healthy vegetation on the VB to withstand the erosive forces of runoff from impervious areas.

Because recreational or playing fields are designed to drain and dry quickly, they should not be used as vegetated buffers. Sheet flow will saturate the turf and soils and make the field unusable.

3.3.2. General Application

A VB is located adjacent to impervious areas and can be used in residential and commercial areas and along highways and roads. Because their effectiveness depends on having an evenly distributed sheet flow over their surface, the size of the contributing area, and the associated volume of runoff have to be limited. Flow can be directly accepted from a parking lot, roadway or building roof, provided the flow is distributed uniformly over the strip. Vegetated Buffers help to reduce somewhat the runoff volume from smaller storms.

3.3.3. Advantages/Disadvantages

3.3.3.1. General

The vegetation can provide aesthetically pleasing green space. In addition, their use adds little cost to a development that has to provide open space, and their maintenance should be no different than routine maintenance of the site's landscaping. Eventually, the vegetated strip next to the spreader or the pavement will have accumulated sufficient sediment to block runoff. At that point in time, a portion of the VB strip will need to be removed and replaced.

Native vegetation and trees within these buffer strips can provide wildlife habitat. Because infiltration occurs, the size of downstream drainage facilities can often be reduced. Gravel underdrains can be used where soils are not suited for infiltration.

3.3.3.2. Physical Site Suitability

The site, after final grading, should have a uniform slope and be capable of maintaining an even sheet flow throughout without concentrating runoff into shallow swales or rivulets. The allowable tributary area depends on the width, length, and the soils that lay under the VB. Hydrologic Soil Groups A and B provide the best infiltration capacity, while Soil Groups C and D provide best site stability. The swelling potential of underlying soils should also be taken into account when used adjacent to structures and pavement. Because of the semi-arid nature of Flagstaff's high plains, a drought tolerant grass cover may be needed to have an effective VB.

3.3.3.3. Pollutant Removal

Pollutant removal depends on many factors such as soil permeability, site slope, the flow path length along the buffer, the characteristics of drainage area, runoff volumes and velocities, and the type of vegetation. The general pollutant removal of both particulate and soluble pollutants is projected to be low to moderate. VBs rely primarily upon the straining through vegetation and settling of solids, and to only a minor degree, on biological uptake and runoff infiltration.

3.3.4. Design Considerations

Design of VBs is based primarily on maintaining sheet-flow conditions across a uniformly graded, irrigated, dense native vegetation cover strip. When a VB is used over unstable slopes, soils, or vegetation, the formation of rills and gullies that disrupt sheet flow will occur. The resultant short-circuiting will invalidate the intended water quality benefits. VBs should be protected from excessive pedestrian or vehicular traffic that can damage the native vegetation cover and affect even sheet-flow distribution. A mixture of native and low water use vegetation and trees may offer benefits for slope stability and improved aesthetics.

3.3.5. Design Procedure and Criteria

The following steps outline the VB design procedure and criteria. Figure 3.1 is a schematic of the facility and its components.

Design Discharge	Determine the 2-year peak flow rate of the area draining to the VB. Also, determine the flow control type; sheet or concentrated.
Minimum Length	Calculate the minimum length (normal to flow) of the VB. The upstream flow needs to be uniformly distributed over this length. General guidance suggests that the hydraulic load should not exceed 0.05 cfs/linear foot of buffer during a 2-year storm to maintain a sheet flow of less than 1 inch throughout dense native and low water use vegetation that is at least 2 inches high. The minimum design length (normal to flow) is therefore calculated as: $$L_G = \frac{Q_{2-year}}{0.05}$$ In which: L_g = Minimum design length (feet) $Q_{2\text{-year}}$ = Peak discharge supplied to the VBs by a 2-year event (cfs) Longer lengths may be used.
Minimum Width	The minimum width (WG) (the distance along the sheet flow direction) of the VB shall be ten feet. A rectangular strip is the preferred shape for the VB and should be free of gullies or rills that concentrate the flow over it.
Maximum Slope	Design slope of a VB in the direction of flow shall not exceed 4 percent.
Flow Distribution	Incorporate a device on the upstream end of the buffer to evenly distribute flows along the design length. Slotted curbing, modular block

	porous pavement (MBP), or other spreader devices can be used to apply flows. Concentrated flow supplied to the VB must use a level spreader (or a similar device) to evenly distribute flow onto the buffer.
Vegetation	Vegetate the VB with native vegetation to promote sedimentation and entrapment and to protect against erosion. The City of Flagstaff Stormwater Section maintains a list of acceptable seed mixes and planting procedures that should be followed.
Outflow Collection	Provide a means for outflow collection. Much of the runoff during significant events will not be infiltrated and will require a collection and conveyance system. A vegetated/rock swale can be used for this purpose and can provide another MDCIA type of a IMP. The buffer can also drain to a storm sewer or to a street gutter. In some cases the use of underdrains can maintain better infiltration rates as the soils saturate and help dry out the buffer after storms or irrigation periods. When underdrains are used, cleanouts should be provided every 100'and long radius (or sweep) fittings used throughout for ease of maintenance. Access for a vaccum truck should be provided to each cleanout.

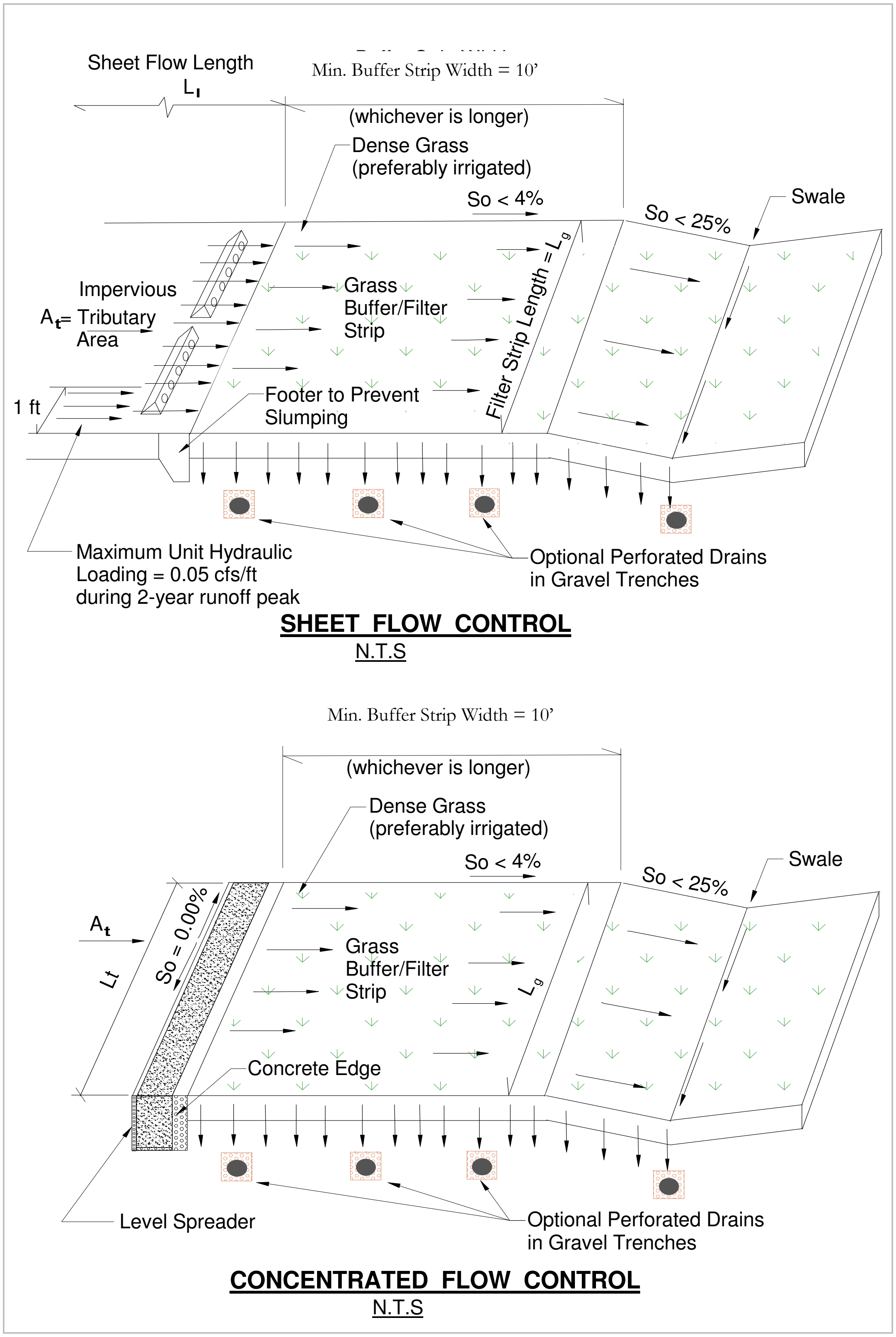


Figure 3.1 - Application of Vegetated Buffers (Filter Strips)

3.4. VEGETATED SWALE / ROCK SWALE

3.4.1. Description

A vegetated/rock swale (VRS) sedimentation facility is an integral part of the MDCIA development concept. They are densely vegetated, or rock lined, drainageways with low-pitched sideslopes that collect and slowly convey runoff. Design of their longitudinal slope and cross-section size forces the flow to be slow and shallow, thereby facilitating sedimentation while limiting erosion. Berms or check dams should be installed perpendicular to the flow as needed to slow it down and to encourage settling and infiltration.

3.4.2. General Application

A VRS can be located to collect overland flows from areas such as parking lots, buildings, residential yards, roadways and vegetated buffer strips (VBs). They can be made a part of the plans to minimize a directly connected impervious area by using them as an alternative to a curb-and-gutter system. A VRS is set below adjacent ground level, and runoff enters the swales over vegetated banks or rundowns. The potential exists for wetland vegetation to become established if the swale experiences standing water or if there is a base flow. If that condition is possible, consider the use of underdrains.

3.4.3. Advantages/Disadvantages

3.4.3.1. General

A VRS, which can be more aesthetically pleasing than concrete or grouted drainage systems, is generally less expensive to construct. Although limited by the infiltration capacity of local soils, this IMP can provide some reduction in runoff volumes from small storms. Native vegetation can reduce flow velocities and protect against erosion during larger storm events. Swales in residential and commercial settings can also be used to limit the extent of directly connected impervious areas.

The disadvantages of using VRSs without underdrains include the possibility of soggy and wet areas in front yards, the potential for mosquito breeding areas, and the potential need for more right-of-way than is needed for a storm sewer.

3.4.3.2. Physical Site Suitability

A VRS is practical only at sites with general ground slopes of less than 4 to 5 percent and are definitely not practical for sites steeper than 6 percent. The longitudinal slopes of a VRS should be kept to less than 1.0 percent, which often necessitates the use of grade control checks or drop structures. Where the general terrain slope exceeds 4 percent, a VRS is often practical only on the upslope side of the adjacent street.

When soils with high permeability (for example, Class A or B) are available, the swale will infiltrate a portion of the runoff into the ground; however, such soils are not required for effective application of this IMP. When Class C and D soils are present, the use of a sand/gravel underdrain is recommended. When underdrains are used, cleanouts should be provided every 100'and long radius (or sweep) fittings used throughout for ease of maintenance. Access for a vaccum truck should be provided to each cleanout.

3.4.3.3. Pollutant Removal

Removal rates reported in the literature vary and fall into the low to medium range[1]. Under good soil conditions and low flow velocities, moderate removal of suspended solids and associated other constituents can be expected. If soil conditions permit, infiltration can remove low to moderate loads of some of the soluble pollutants when flow velocities are very low. As a result, small frequently occurring storms can benefit the most.

3.4.4. Design Considerations and Criteria

A VRS is sized to maintain a low velocity during small storms and to collect and convey larger runoff events, all for the projected fully developed land use conditions. If the design flows are not based on fully developed land conditions, the swales will be undersized and will not provide the intended pollutant removal, flow attenuation, or flow conveyance capacity.

Judicious use of VRSs can replace both the curb-and-gutter systems and greatly reduce the storm sewer systems in the upper portions of each watershed when designed to convey the "initial storm" (for example, a 2- or a 5-year storm) at slow velocities. However, if one or both sides of the VRS are also to be used as a VB, the design of the VB has to follow the recommendations of Section 3.3, Vegetated Buffer Strip.

3.4.5. Design Procedure and Criteria

The following steps outline the VRS design procedure and criteria.

1. Design Discharge	Determine the 2-year flow rate to be conveyed in the VRS.
2. Swale Geometry	Select geometry for the VRS. The cross section should be either trapezoidal or triangular with side slopes flatter than 4:1 (Horizontal/ Vertical), preferably 5:1 or flatter. The wider the wetted area of the swale, the slower the flow and the more effective it is in removing pollutants.
3. Longitudinal Slope	Maintain a longitudinal slope of the VRS between 0.2 and 1.0 percent. If the longitudinal slope requirements can not be satisfied with available terrain, grade-control checks or small drop structures must be incorporated to maintain the required longitudinal slope. If the slope of the swale exceeds 0.5 percent the swale must be vegetated or lined.
4. Flow Velocity and Depth	Calculate the velocity and depth of flow through the swale. Using the Manning's equation and a Manning's roughness coefficient of n=0.05 to 0.06, find the channel velocity and depth using the peak 2-year flow rate determined in Step 1. Maximum flow velocity in the swale shall not exceed 1-foot per second and the maximum flow depth shall not exceed 1-foot at the 2-year peak flow rate. If these conditions are exceeded, repeat steps 2 through 4 each time altering the depth and bottom width or longitudinal slopes until these criteria are satisfied.
5. Vegetation	Vegetate the VRS with native or low water use vegetation or line with rock to promote sedimentation, filtration, and

nutrient uptake, and to limit erosion through maintenance of low flow velocities. The City of Flagstaff Stormwater Section maintains a list of acceptable seed mixes and planting procedures that should be followed.

6. Drainage and Flood Control

Check the water surface during larger storms such as the 10-year through the 100-year floods to ensure that drainage from these larger events is being handled without flooding critical areas or residential, commercial, and industrial structures and/or the adjacent streets.

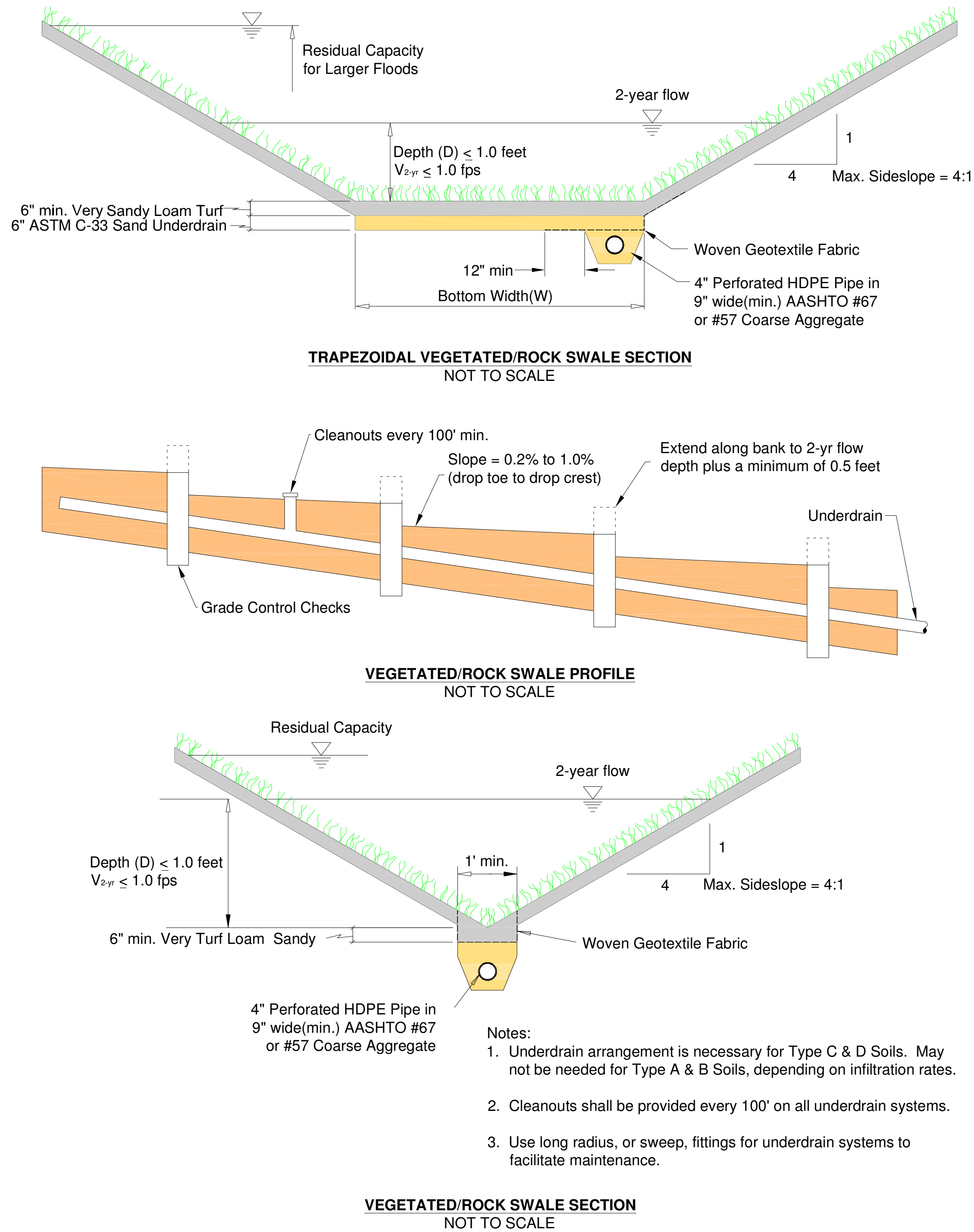


Figure 3.2 - Vegetated/rock swale – Profile and Sections
(Based on drawing from UDFCD)

3.5. POROUS PAVEMENTS

3.5.1. Porous Pavement–General Description

Porous Pavement (PP) covers a variety of stabilized surfaces that can be used for the movement and parking of vehicles (automobiles, trucks, construction equipment, light aircraft, etc.) and storage of materials and equipment. It differs from conventional pavement in that it is designed to infiltrate stormwater runoff instead of shedding it off the surface. Porous Pavement offers the advantage of decreasing the imperviousness of an urbanizing or redevelopment site, thereby reducing runoff and pollutant loads leaving the site.

Conventional Concrete and Asphalt

Conventional concrete and asphalt (technically known as Portland cement concrete and asphaltic concrete, respectively) are impervious pavements widely used in site development. Because of their ease of installation, flexibility, durability, economy, and load bearing capabilities, concrete and asphalt are the most commonly used pavement materials. With a runoff coefficient of near 1.0, conventional concrete and asphalt pavements are principal contributors to impervious land coverage in most development. In site design for stormwater quality, these materials are best used sparingly. If more permeable pavement materials cannot be used, minimizing the area of concrete and asphalt surfaces through clustering and other techniques will reduce the resulting impervious land coverage. For remaining area, designing asphalt and concrete pavement surfaces to slope towards pervious areas instead of into directly-connected collection structures will reduce their negative impact on water resources.

Porous Pavement s can be designed with and without underdrains. Whenever underdrains are used, infiltrated water will behave similarly to interflow and will surface at much reduced rates over extended periods of time. Cleanouts should be provided every 100 feet at a minimum and long radius (or sweep) fittings should be used to facilitate underdrain maintenance. Access for a vaccum truck should be provided to each cleanout.

All types of Porous Pavement help to return stormwater runoff hydrology to more closely resemble pre-developed conditions. The designer needs to consult with a geotechnical engineer as to the suitability of each type of Porous Pavement for the loads and traffic it will support and carry, and the geologic conditions the pavement will rest upon. All Porous Pavements must comply with environmental standards and should be correctly designed, installed and maintained in order to provide structural integrity and longevity.

What follows is a description of five types of porous pavement and defines their acronyms. These will be used throughout the remainder of this section of the *Manual*:

3.5.1.1. Modular Block Pavers (MBP)

This pavement (also known as open-cell concrete pavers) consists of concrete block units with open surface voids laid on a gravel subgrade with open surface voids. These voids occupy at least 20% of the total surface area and are filled with sand (ASTM C-33 sand fine concrete aggregate or mortar sand) or sandy loam turf that has at least 50% sand by weight in its volume. However, unless the pavement will be watered regularly (i.e., using a sprinkler system) to keep

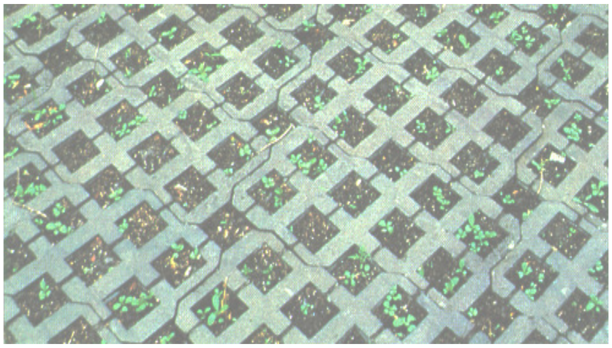


Photo from UDFCD

the vegetation viable, concrete sand infill is the recommended material. A number of commercially available pavers have over 40% of total surface area as open voids that can be filled with sand or sandy loam-sand mix.

MBP may be sloped or flat. MBPs have been in use in United States since the mid-1970s. Although field data that quantify their long-term performance are somewhat limited, data collected in the Denver area, and other parts of the United States, and episodic reports from Canada, Australia, Asia, and Europe, indicate that properly installed MBPs are reliable and have experienced few problems under a wide range of climates.

An alternate application of MBP provides for a surcharge zone above its surface to detain runoff and provide storage space for the runoff capture volume (*ROCV*). This type of application is described in Section 3.6 Porous Pavement Detention (PPD).

3.5.1.2. Permeable Interlocking Concrete Pavers (PICP)

This pavement consists of concrete block units replicating the appearance of cobblestone that create open voids by beveling the corners of each block and/or wider spacing between the blocks. One of the commercial "cobblestone" products that meets this description is Eco-stone™ made by Pavestone Co®. These "cobblestones" are laid on a gravel subgrade. The surface area has voids that occupy at least 8% of the total surface area and are filled with medium sized aggregate.

Photo from UDFCD

PICP may also be laid on a sloped or on a flat grade. This type of pavement has been in use since the 1980s. Field data that quantify the long-term performance of PICP are limited; however, the data and the episodic reports from other parts of the United States, Canada, Australia, Asia and Europe indicate that when properly installed, PICP is reliable and has experienced few problems under a wide range of climates. Because of the limited net open area this pavement surface provides, it is not recommended for use in *Porous Pavement Detention* installations.

3.5.1.3. Reinforced Grass Pavement (RGP)

This is a stabilized grass surface intended for use in parking lots that experience intermittent use. It has been shown to function well under wet-weather conditions and, when properly designed and installed, it will infiltrate rainwater at rates that equal or exceed the infiltration rates of NRCS Hydrologic Soil Group Type B soils. This IMP is not recommended for heavy vehicles with many turning movements as the reinforcing grid may be damaged. The grasses need to be mowed on a cycle that depends on the grass types and whether or not irrigation is used. Use of irrigated grasses should be considered for more actively-used parking lots.

Photo from Invisible Structures, Inc®.

One of the commercial products that meets this description is *Reinforced Grass*. It is grass turf reinforced with plastic rings and filter fabric underlain by gravel and is known as Grasspave2™ by Invisible Structures, Inc®. Other commercial systems are also available and should be investigated for applicability to the site being developed or redeveloped.

3.5.1.4. Poured Porous Concrete Pavement (PCP)

This is a monolithically poured porous concrete pavement that has 15% to 21% of its volume as void ratio. These voids within the concrete are achieved by the eliminating of the fine sand aggregate from the concrete mix. They provide the flow paths for rainwater from the surface of the pavement to the Base Course underlying it. Because the integrity of the concrete structure may be harmed by standing water during freezing weather, the use of PCP is not recommended for use in *Porous Pavement Detention* installations.

PCP Parking lot at University of Northern Arizona's Applied Research and Development Facility

It is critical that sufficient aggregate Base Course layer is provided under the porous concrete slab to store the runoff and allow it to infiltrate slowly into the ground or be drained using an underdrain pipe system. Having a sufficiently thick layer of aggregate Base Course is particularly critical during the months of the year when freezing of water can occur. When the water under the porous pavement slab is permitted to rise into the slab, freeze and thaw cycles can break the cementatious bonds between the stones in the pavement; causing it to fail. On the other hand, when each of the layers of the PCP is properly designed and constructed, and well maintained, it should provide good structural integrity and longevity.

3.5.1.5. Porous Asphalt (PA)

Porous asphalt (PA) has been analyzed by the EPA since the 1970's and may be substituted for conventional pavement on parking areas and areas of light traffic provided the grades, subsoil, drainage characteristics, and groundwater conditions are all suitable. PA consists of an open graded Hot Mix Asphalt (HMA) that contains less than 3% of fines passing a number 200 U.S. Standard Sieve, and is placed over an infiltration bed. This HMA is prepared with a specific asphalt binder percentage by dry weight aggregate to test draindown, air voids and abrasion. The optimum asphalt cement content should be determined by graphing the percent asphalt versus specified criteria for a minimum of 3 contents before the final mix is subsequently tested for moisture susceptibility and resistance to stripping. (Up to 20% of reclaimed asphalt pavement may also be used in the HMA mix, with a uniform quality while adhering to the aggregate gradation specified for the HMA mixture.)

The infiltration bed is comprised of a top choker coarse aggregate layer, a middle coarse aggregate layer and a bottom sand bed layer. As with any asphalt pavement installed in Flagstaff, the freeze/ thaw cycles and the expansive soils must be taken into account. It is recommended that PA be placed between April and October (when the ambient air temperature is 55 degrees Fahrenheit or greater) with an underdrain trench and an impermeable liner where applicable, to address these issues.

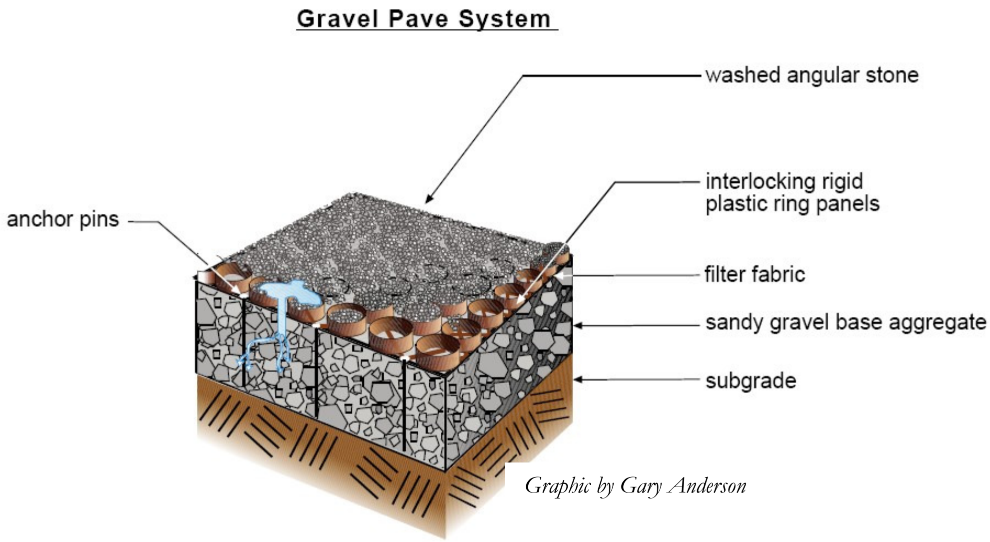
3.5.1.6. Reinforced Porous Gravel Pavement (RPGP)

This is a stabilized gravel surface paving that is appropriate for reduced speed and limited frequency of traffic areas such as driveways, parking lots, pathways, etc. The top gravel layer is reinforced with a plastic grid and filter fabric. This grid is underlain by a layer of Base Course aggregate that adds structural support and acts as a reservoir for runoff. This IMP is not recommended for heavy vehicles with many turning movements as the reinforcing grid may be damaged.

Grand Canyon Trust Gravelpave Parking Lot

Because the integrity of the gravel surface is not likely to be harmed by standing water during freezing weather, this pavement surface can also be used in *Porous Pavement Detention* installations. It is imperative that there is sufficient aggregate Base Course to store the runoff and allow it to infiltrate slowly into the ground or be slowly drained using an underdrain pipe system. When each of the layers of the RPGP is properly designed and constructed, it should provide good structural integrity and longevity.

RPGP has a relatively simple cross-section to construct and should not be difficult or expensive to rebuild when its performance begins to degrade over time.



Graphic by Gary Anderson

3.5.2. Potential Applications

3.5.2.1. Modular Block and Permeable Interlocking Concrete Pavments (MBP & PICP) and Reinforced Porous Gravel Pavement (RPGP)

MBP, PICP, and RPGP types of pavements are best suited for use in low vehicle movement zones, such as roadway shoulders, driveways, parking strips and parking lots. Vehicle movement (i.e., not parking) lanes that lead up to one of these types of porous pavement parking pads may be better served, but not always, by solid asphalt or concrete pavement.

The following are potential applications for these types of porous pavement: The following figure depicts typical applications of MBP, PICP, and RPGP types of pavement in various parking lot and roadway configurations.

- Low vehicle movement zones in airports such as parking lots, aprons and maintenance roads
- Crossover/emergency stopping/parking lanes on divided highways
- Residential street parking lanes
- Private and public building driveways
- Maintenance roads and trails
- Roadway shoulders and parking lanes
- Emergency vehicle and fire access lanes
- Low vehicle movement commercial and industrial parking lots, including driveways
- Light commercial/retail/industrial parking lots
- Equipment storage areas

3.5.2.2. Reinforced Grass Pavement (RGP)

RGP type of pavement is best used in overflow parking zones or in parking lots that experience occasional uses (e.g., once-a-week-used portions of church and football stadium parking lots), roadway shoulders, residential street parking lanes, and emergency vehicle access lanes. Vehicle movement lanes (i.e., not parking pads themselves) that lead up to one of these RGP surfaces need to be served by solid asphalt or concrete pavement, or by PCP type of pavement. The following are potential applications for this type of porous pavement:

- Crossover/emergency stopping/parking lanes on divided highways
- Roadway shoulders and parking lanes
- Maintenance roads and trails
- Emergency vehicle and fire access lanes
- Commercial/retail/industrial parking lot overflow areas
- Church parking areas more remote from buildings
- General aviation airport landing strips, parking lots, aprons and maintenance roads

3.5.2.3. Porous Concrete and Porous Asphalt Pavemenst (PCP & PA)

The use of PCP type of pavement has the fewest restrictions on the types of traffic it may carry and may be used for vehicle movement lanes that have very light traffic and for parking areas in residential and commercial developments. Its use is not recommended for vehicle travel lanes or collector and arterial streets, while it may be considered for use in parking lanes and shoulders of these roadways. The following are potential applications for PCP:

- Commercial/retail/industrial parking lots
- Emergency vehicle and fire access lanes
- Maintenance roads and trails
- Church parking area lots
- Residential street parking lanes and driveways
- Crossover/emergency stopping/parking lanes on divided highways
- General aviation airport taxiways, parking lots, aprons and maintenance roads

3.5.3. Advantages/Disadvantages

3.5.3.1. General

Aside from the potential for particulate pollutant removal, PPs of all types can dramatically reduce the surface runoff from most rainstorms and snowmelt events and virtually eliminate surface runoff from smaller storms. These reductions in runoff volumes translate directly to proportional reductions in pollutant loads leaving the site. Its use can result in stormwater surface runoff conditions that approximate the predevelopment site conditions, something that can be used in selecting surface retention and infiltration parameters that are close to pre-developed conditions when using stormwater runoff hydrologic models.

Even when underdrains are used, the response time of runoff is significantly delayed and approaches the characteristics of what hydrologists call *interflow*. As a result, drainage and downstream flooding problems can be significantly reduced. These can translate in savings since the downstream facilities needed to address site runoff, such as *ROCV*, detention volumes and conveyance facilities can be smaller.

Another advantage that the use of PP offers is that creative selection by land planners and landscape architects of PP materials, patterns and colors can also provide aesthetic enhancements to what often are very mundane surfaces.

The primary disadvantage of PP is that they cost more to install and maintain than conventional concrete or asphalt pavement. These added costs can be somewhat offset by the cost savings in the downsizing of on-site and downstream drainage systems and facilities such as detention basins, numbers of inlets, storm sewers and channels. Other disadvantages of PPs, except for PCP and PA, can include uneven driving surfaces and potential inconvenience of walking on these types of surfaces in high heel shoes. PP is not recommended in areas where wind erosion supplies significant amounts of windblown sediment.

3.5.4. Design Considerations

3.5.4.1. Physical Site Suitability and Need for Underdrains

All types of PP can be installed even when free draining subsoils are not present at the site by providing them with underdrains. An underdrain insures that the gravel subgrade is drained when the subsoils or site conditions do not allow infiltration.

In the case where the installation is located on top of expansive soils, the installation of an impermeable liner along with underdrains is strongly recommended. The liner is needed to prevent wetting the underlying expansive clays. In addition, PPs installed over expansive soils should not be located adjacent to structure foundations in order to reduce the potential for damages to structures.

Porous pavements should not be used whenever commercial or industrial sites may have activities, or processes, that could result in the storage and/or handling of toxic or caustic chemicals, fertilizers, petroleum products, fats, or greases. Such products or materials that come into contact with stormwater could infiltrate into the ground.

3.5.4.2. MBP and PICP Installations

There are many block patterns that may be used for MBP, provided they have at least 20 percent (≥ 40% preferred) of their surface area as open annular spaces. This is the minimum open surface area in this *Manual* to be considered as an MBP. Permeable Interconnected Concrete Pavers shall have at least eight percent (8%) of its surface area as open annular spaces to qualify as a PICP under the recommendations of this *Manual*. It is critical that the runoff from the tributary impervious surfaces be evenly distributed over the MBP and PICP porous surfaces.

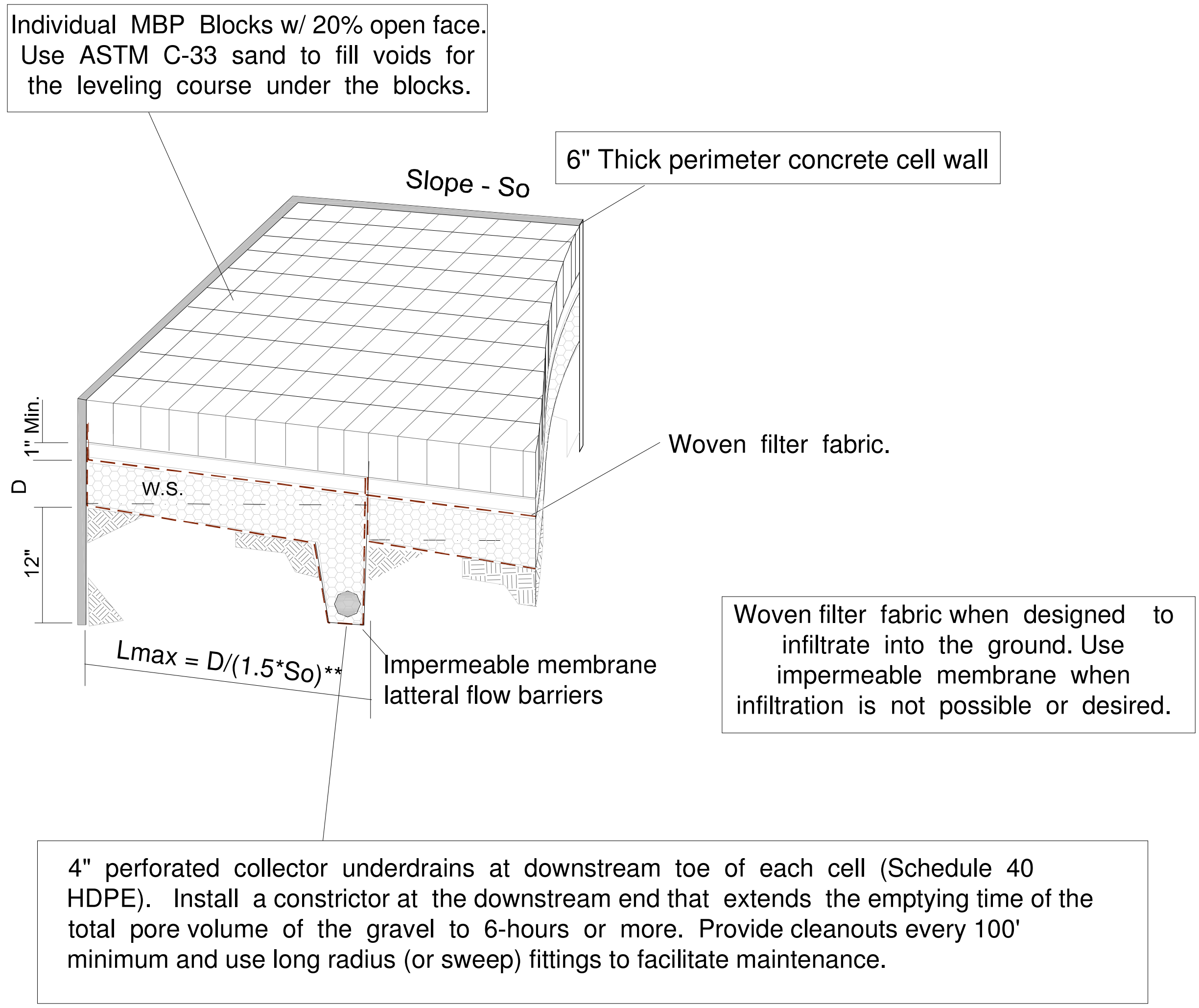


Figure 3.3 - Isometric View of Modular Block Pavement (MBP) Installation

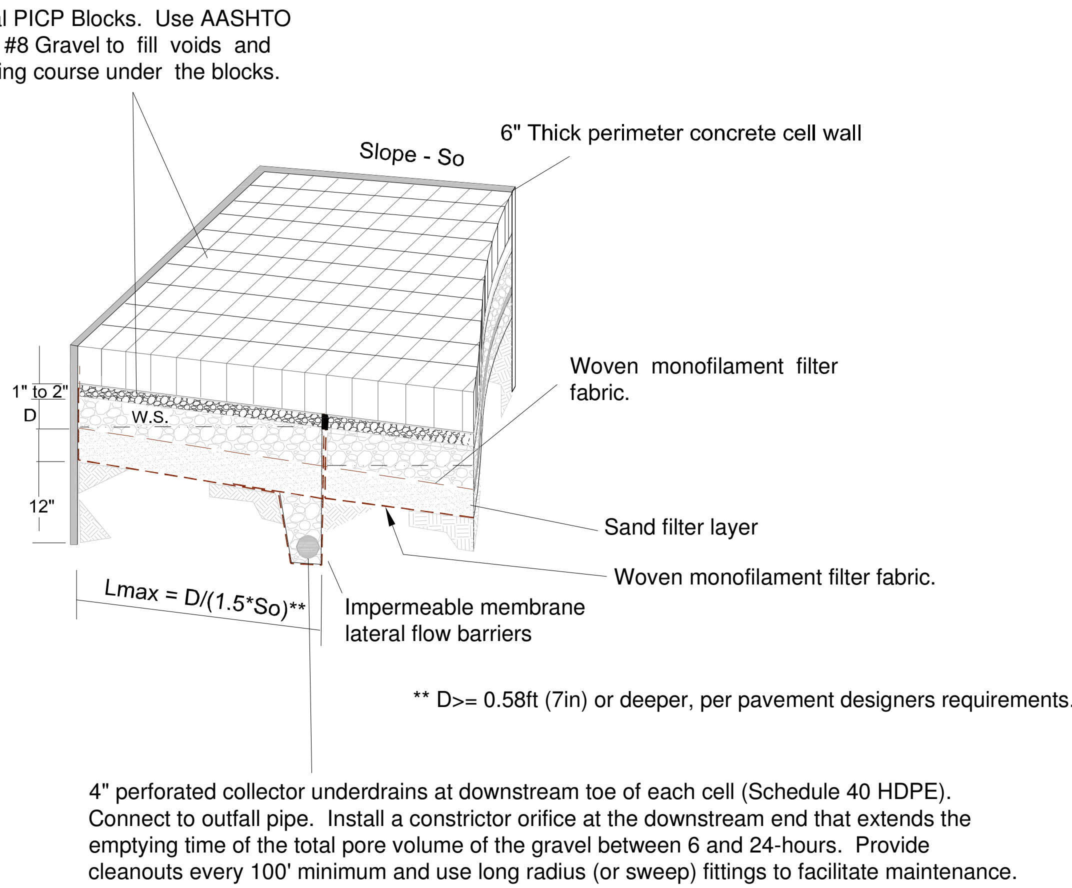


Figure 3.4 - Isometric View of Porous Interconnected Paver Pavement (PICP) Installation.

3.5.4.3. RGP Installations

The following figures show typical cross-sections and details for one type of Reinforced Grass Pavement (RGP); the one based on a product called Grasspave2™ by Invisible Structures, Inc. Other products that achieve the same end goal and structural stability are also available. Regardless of which brand of RPG product is used, the manufacturer's instructions should be closely followed except as called for differently in this *Manual*. The modifications in this *Manual* include the installation of an AASHTO #67 compacted gravel layer and non-woven geotextile fabric under this gravel layer.

3.5.4.4. PCP Installations

Figure 3.9 illustrates recommended cross-sections for Porous Concrete Pavement (PCP) installations. The top part of the figure is for areas underlain by NRCS Type D soils or for use in areas serving catchments with land uses that have potential for groundwater contamination. It is critical that the builders strictly enforce the concrete mix and placement specifications for this type of pavement provided in the TYPICAL STRUCTURAL IMP SPECIFICATIONS appendix of this *Manual*, which are in large part based on the samples specifications provided by the Georgia Concrete & Products Association (GCPA, 1997) and modified for the climate and geologic conditions found in the Flagstaff area.

3.5.4.5. PA Installations

Proper site evaluation shall take place prior to approval of a site for the PA application, and shall include tests for soil permeability, porosity, depth of seasonal high water table, and depth to bedrock. Slopes should be flat or very gentle and shall not exceed 5%. Minimum EPA requirements that must be met for site consideration include:

- Subdrains must be used if the infiltration rate 3.0 feet below infiltration bed of is not at least 1.0 in/hr .
- Depth to bedrock and seasonally high water table at least 4.0 feet.
- Setback from building foundations at least 10 feet down gradient and 100 feet up gradient.

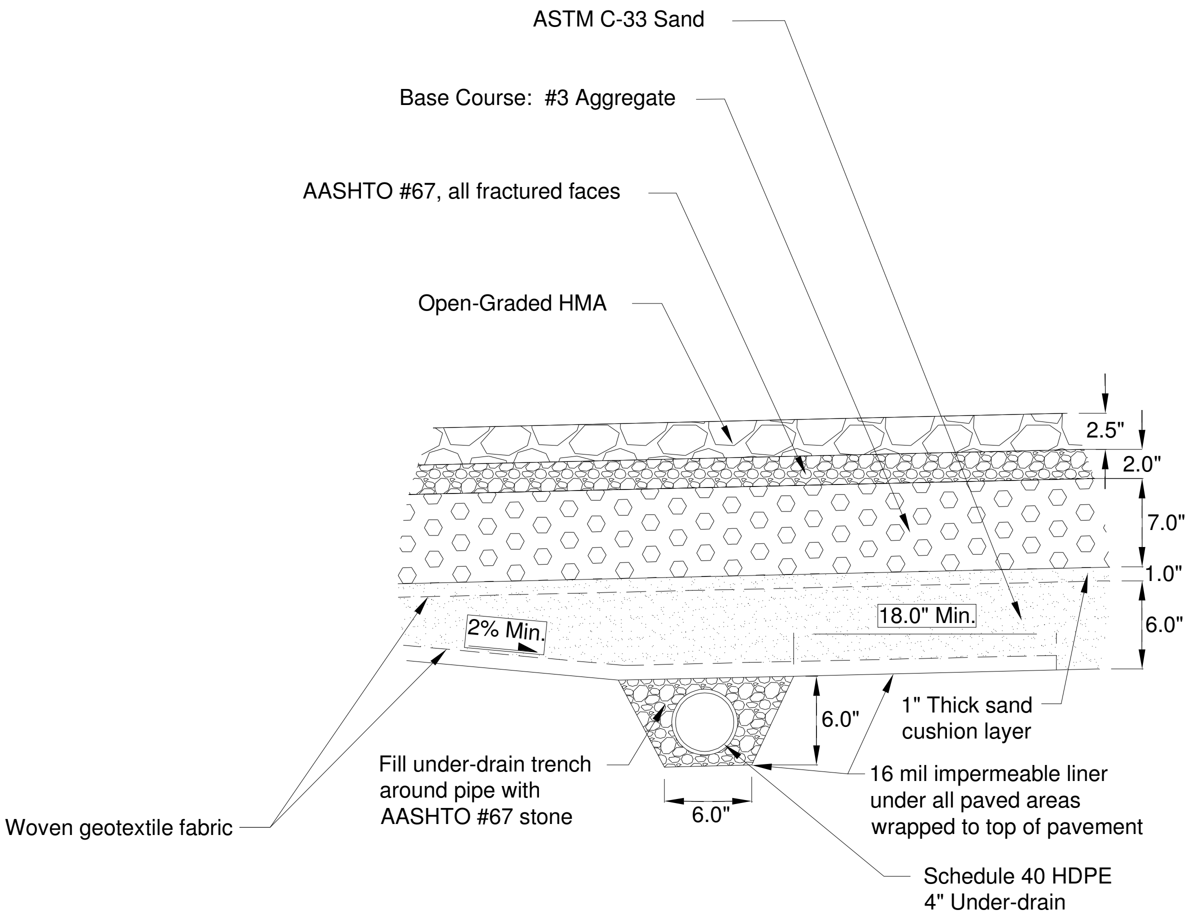


Figure 3.5 - Porous Asphalt (PA) - Typical Cross-Section

For installation practices it is essential to use adequate skilled laborers who are thoroughly trained and experienced in the necessary crafts and who are completely familiar with the specified requirements and methods needed for proper performance. It is critical that the builders strictly enforce the mix and placement specifications for this type of pavement provided in this Manual. Figure 3.5 illustrates a cross-section for Porous Asphalt installation. All mixture designs should be in accordance with AASHTO procedures. The contractor shall submit a certification letter from the polymer-modified supplier to the Engineer before the mix is placed.

3.5.4.6. RPGP Installations

Figure 3.10 illustrates recommended cross-sections for Reinforeced Porous Gravel Pavement (RPGP) installations. The top part of the figure is for areas underlain by NRCS Type D soils or for use in areas serving catchments with land uses that have potential for groundwater contamination. It is critical that the builders strictly follow the recommendations for this pavement presented in the sections that follow.

3.5.5. Design Procedures and Criteria

3.5.5.1. Modular Block Pavement (MBP) Installations

Select Blocks	Select MBP that have 20% or more (40% preferred) of the surface area open. Follow Manufacturer's installation instructions, except that Porous Pavement Infill and Base Course materials and dimensions specified in this section shall be strictly adhered to.
Infill materials and Leveling Course	The MBP openings shall be filled with ASTM C-33 graded sand or very sandy loam and shall be placed on a one-inch thick leveling course of C-33 sand. The use of locally available recycled glass is also acceptable if the designer proposes it.
Base Course	The *Base Course* shall be AASHTO No. 3 coarse aggregate; all fractured surfaces. For volume calculations assume 30 percent of total volume to be open pore space. Unless an underdrain is provided, at least 6-inches of the subgrade underlying the Base Course shall be sandy and gravely material with no more than 10% clay fraction.
Geotextile Fabric on Top of the Base Course	Place a woven geotextile fabric over the *Base Course* shown in the detail drawing. Use a geotextile material that meets the following requirements: ASTM D-4751 - AOS U.S. Std. Sieve #50 to #70 and D-4633 – Trapezoidal tear strength $\geq$ 100 x 60 lbs; COE specified minimum open area $\geq$ 4%
Geotextile Fabric or Impermeable Liner Under the Base Course	When expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 16 mil thick, or heavier, liner on the bottom and sides of the basin under the pavement. If soils are not expansive (i.e., NRCS Type A, B or C), use a woven geotextile material that meets the requirements specified under item 4 above. Products that meet these requirements are: US Fabric US 2070 and US 670, Mirafi Filterweave 500 and 700, Carthage Mills Carthage 6%.

Geotextile Fabric & Membrane Installation	Place by rolling fabric parallel to the contours starting at the most downstream part of the pavement. Provide a minimum of 18-inches of overlap between adjacent sheets. Bring up geotextile and impermeable membrane to the top of perimeter walls. Attach membrane and fabric to perimeter walls with roofing tar or other adhesive or concrete anchors. Provide sufficient slack in the geotextile and membranes to prevent stretching them when sand and/or rock is placed. Seal all joints of impermeable membrane to be totally leak free.
Perimeter Wall	Recommend that a concrete perimeter wall be installed to confine the edges of the MBP block areas as shown in the detail drawings.
Contained Cells – Lateral Flow Barriers	Install lateral-flow cut-off barriers using 16 mil, or thicker, PE or PVC membrane liner or concrete walls installed parallel to the contours (i.e., normal to the flow) to prevent flow of water downstream and then surfacing at the toe of the PP installation. Distance (L_{MAX}) between these cut-off barriers shall not exceed:

$$L_{MAX} = \frac{D}{1.5 \bullet S_O}$$

in which, L_{MAX} = Maximum distance between cut off membrane normal to the flow (ft.),

S_O = Slope of the Base Course (ft/ft),
D = Depth of gravel *Base Course* (ft).

Subdrain System	When the MBP is located on NRCS Type D soils, when the Type B or C soil sub-base is to be compacted for structural reasons, or when an impermeable membrane liner is needed, install a subdrain system using Schedule 40 HDPE pipe. Locate each perforated pipe just upstream of the lateral-flow cut-off barrier. Do not exceed 20-foot spacing. Use a control orifice sized to drain the pore volume of empty each cell between 6-hours and 24-hours. Provide cleanouts at a minimum of every 100' and use long radius (or sweep) fittings to facilitate maintenance. Access for a vaccum truck should be provided to each cleanout.
Design Area Ratio	The design area ratio shall not exceed 2.0 (ratio = contributing impervious area divided by porous pavement area).

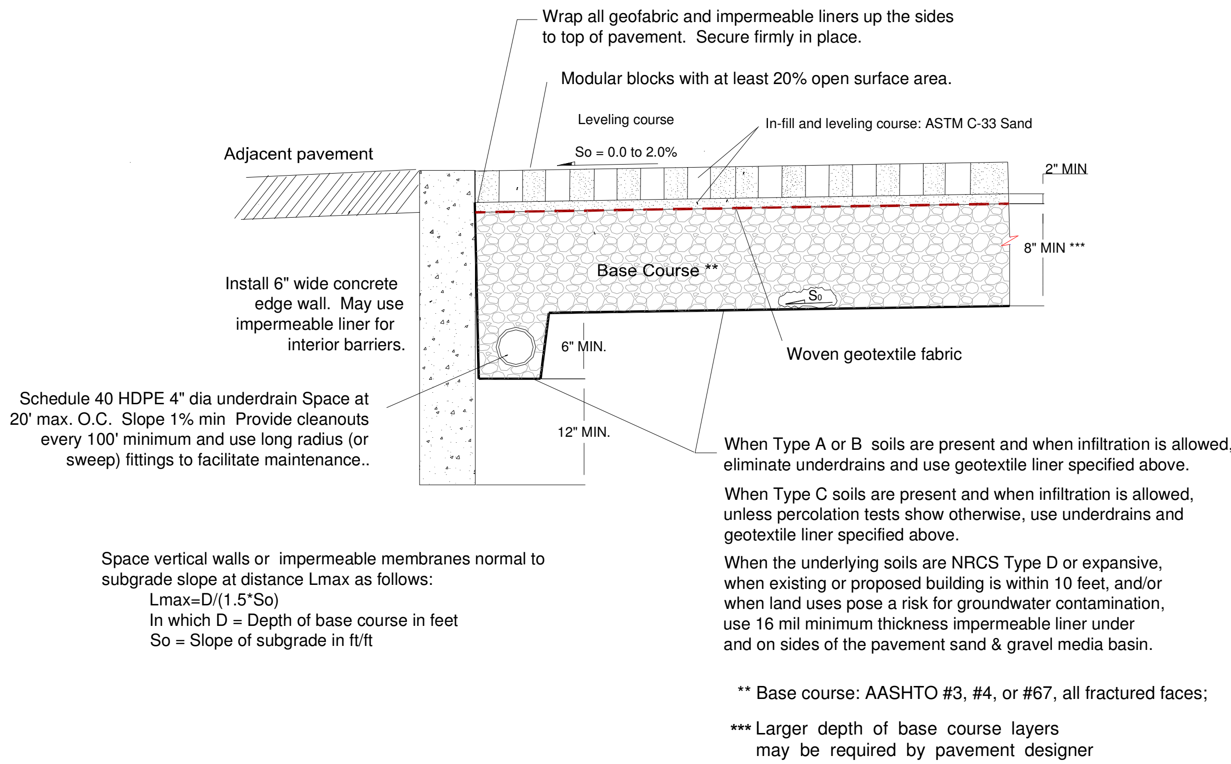


Figure 3.6 - Modular Block Pavement (MBP) – Typical Cross-Section

3.5.5.2. Permeable Interlocking Concrete Pavement (PICP) Installations

Select Blocks

Select PICP blocks that have 8% or more of the surface area open. Follow Manufacturer's installation instructions, except that Porous Pavement Infill and Base Course materials and dimensions specified in this section shall be strictly adhered to.

Infill materials and Leveling Course

The PICP openings shall be filled with AASHTO No. 8 fractured aggregate and shall be placed on a two-inch thick leveling course of same No. 8 aggregate. The use of locally available recycled glass is also acceptable if the designer proposes it.

Base Course

The *Base Course* shall be AASHTO No. 67 or ASTM No. 57 coarse aggregate; all fractured surfaces. For volume calculations assume 30 percent of total volume to be open pore space (see Figure 3.7). Unless an underdrain is provided, at least 6-inches of the subgrade underlying the *Base Course* shall be sandy and gravely material with no more than 10% clay fraction.

Bottom Sand Layer	Bottom sand layer shall be ASTM C-33 sand and will be installed under the base course and above the underdrain trench. The use of locally available recycled glass is also acceptable if the designer proposes it.
Geotextile Fabric on Top of the Base Course	Place a woven geotextile fabric on top of the Base Course as shown in Figure 3.7.
Geotextile Fabric or Impermeable Liner Under the Base Course	When expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 16 mil thick, or heavier, liner on the bottom and sides of the basin under the pavement. If soils are not expansive (i.e., NRCS Type A, B or C), use a woven geotextile material.
Geotextile Fabric & Membrane Installation	Place by rolling fabric parallel to the contours starting at the most downstream part of the pavement. Provide a minimum of 18-inches of overlap between adjacent sheets. Bring up geotextile and impermeable membrane to the top of perimeter walls. Attach membrane and fabric to perimeter walls with roofing tar or other adhesive or concrete anchors. Provide sufficient slack in the geotextile and membranes to prevent stretching them when sand and/or rock is placed. Seal all joints of impermeable membrane to be totally leak free.
Perimeter Wall	Recommend that a concrete perimeter wall be installed to confine the edges of the MBP or PICP block areas as shown the detail drawings.
Contained Cells – Lateral Flow Barriers	Install lateral-flow cut-off barriers using 16 mil, or thicker, PE or PVC membrane liner or concrete walls installed parallel to the contours (i.e., normal to the flow) to prevent flow of water downstream and then surfacing at the toe of the PP installation. Distance (L_{MAX}) between these cut-off barriers shall not exceed:

$$L_{MAX} = \frac{D}{1.5 \bullet S_O}$$

in which, L_{MAX} = Maximum distance between cut off membrane normal to the flow (ft.),

S_O = Slope of the Base Course (ft/ft),

D = Depth of gravel *Base Course* (ft).

Subdrain System — When the PICP is located on NRCS Type D soils, when the Type B or C soil sub-base is to be compacted for structural reasons, or when an impermeable membrane liner is needed, install a subdrain system using Schedule 40 HDPE pipe. Locate each perforated pipe just upstream of the lateral-flow cut-off barrier. Do not exceed 20-foot spacing. Use a control orifice sized to drain the pore volume of empty each cell between 6-hours and 24-hours. Provide cleanouts at a minimum of every 100' and use long radius (or sweep) fittings to facilitate maintenance. Access for a vaccum truck should be provided to each cleanout.

Design Area Ratio — The design area ratio shall not exceed 2.0 (ratio = contributing impervious area divide by porous pavement area).

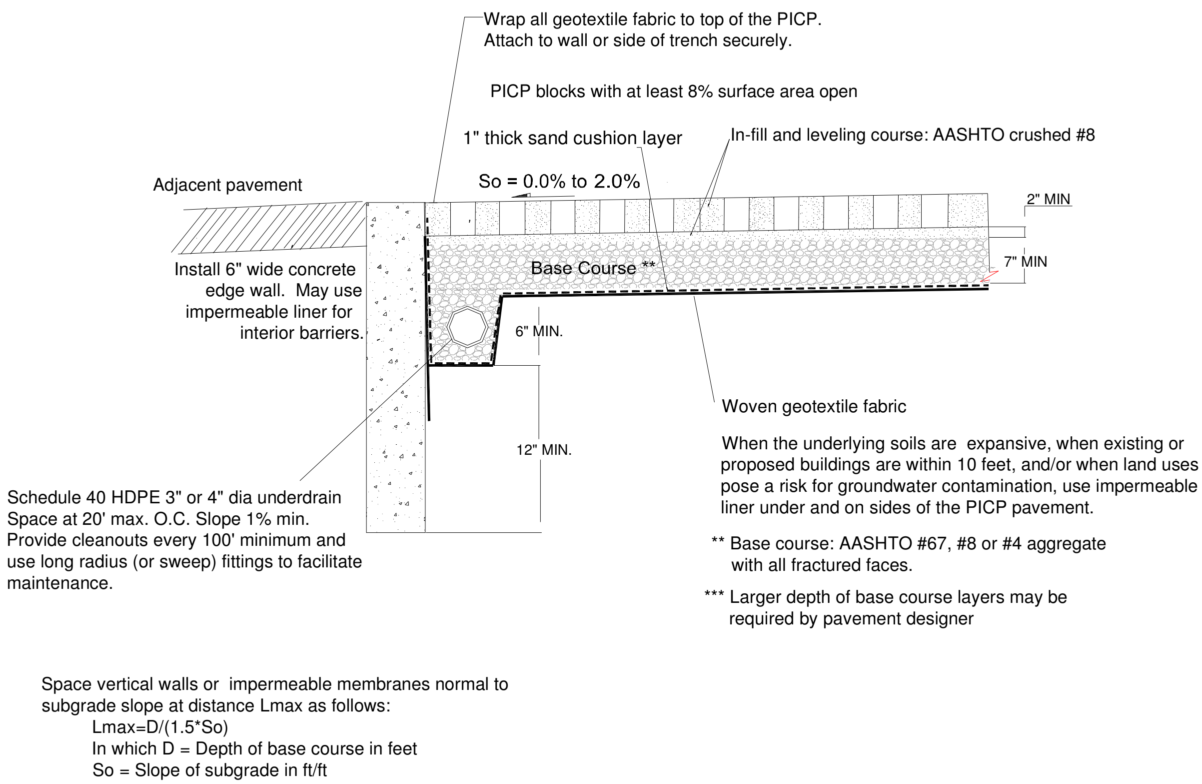
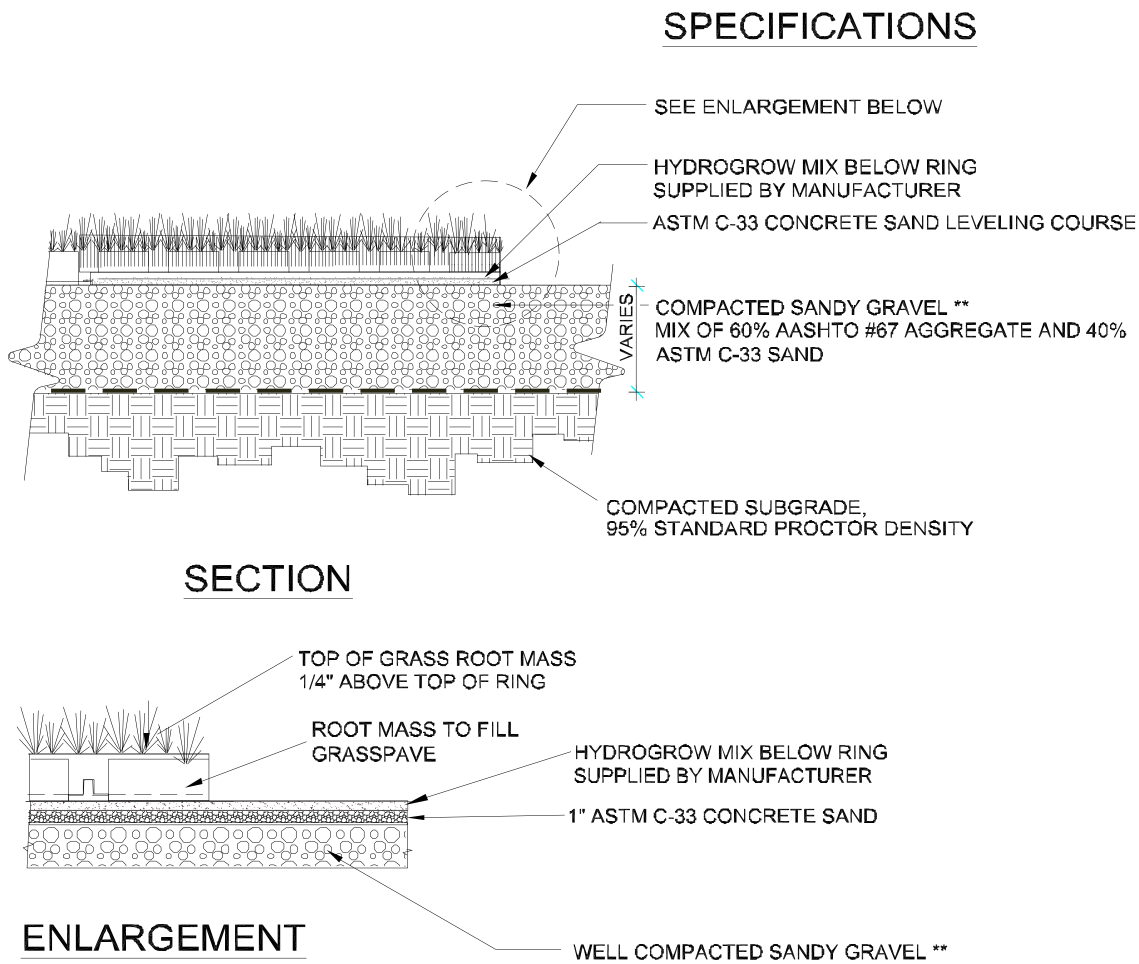


Figure 3.7 – Permeable Interlocking Concrete Pavement (PICP) – Typical Cross-Section

3.5.5.3. Reinforced Grass Pavement (RGP) Installations.

Base Course for Reinforced Grass	Provide the required Base Course of AASHTO No. 67 or ASTM No. 57 coarse aggregate for the Reinforced Grass type of RGP. The aggregate shall have all fractured surfaces.
Geotextile Fabric	No fabric or liner required for RGP installations.
Geotextile Fabric Under the Base Course	For Reinforced Grass type of RGP, and when expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 16 mil thick, or heavier, liner on the bottom and sides of the basin under the pavement. If soils are not expansive (i.e., NRCS Type A, B or C), use a woven geotextile material
Geotextile Fabric & Membrane Installation	Place by rolling fabric parallel to the contours starting at the most downstream part of the pavement. Provide a minimum of 18-inches of overlap between adjacent sheets. Bring up geotextile and impermeable membrane to the top of perimeter walls. Attach membrane and fabric to perimeter walls with roofing tar or other adhesive or concrete anchors. Provide sufficient slack in the geotextile and membranes to prevent stretching them when sand and/or rock is placed. Seal all joints of impermeable membrane to be totally leak free.
Vegetation	Vegetate the RGP with native or low water use grasses. The City of Flagstaff Stormwater Section maintains a list of acceptable seed mixes and planting procedures that should be followed.
Subdrain System	When the RGP is located on NRCS Type D soils, when the Type B or C soil sub-base is to be compacted for structural reasons, or when an impermeable membrane liner is needed, install a subdrain system using Schedule 40 HDPE pipe. Locate each perforated pipe just upstream of the lateral-flow cut-off barrier. Do not exceed 20-foot spacing. Use a control orifice sized to drain the pore volume of empty each cell between 6-hours and 24-hours. Provide cleanouts at a minimum of every 100' and use long radius (or sweep) fittings to facilitate maintenance. Access for a vaccum truck should be provided to each cleanout.
Design Area Ratio	The design area ratio shall not exceed 2.0 (ratio = contributing impervious area divide by porous pavement area).



NOTES:

1. INSTALL GRASS TURF REINFORCING LAYER PER MANUFACTURER'S RECOMMENDATIONS INCLUDE MODIFICATIONS SHOWN ON THIS DRAWING.

2. DETAIL BASED ON INVISIBLE STRUCTURES, INC., ET AL DETAILS, BUT MODIFIED TO SUIT USDCM REQUIREMENTS.

** DEPTH OF PAVEMENT DETERMINIED BY PAVEMENT DESIGNER

Figure 3.8 - Typical Reinforced Grass Pavement Detail

3.5.5.4. Porous Concrete Pavement (PCP) Installations.

Design PCP Thickness	Design the thickness of the porous concrete slab to support the traffic and vehicle types the pavement will have to carry.
PCP Mix and Installation	Mix of ASSHTO #67 or #8 Aggregate and Portland Cement. Use low cement/water ratio and no less than 6.5 sacks of Portland Cement per yard. No fly ash shall be used. Strictly adhere to the porous concrete mix specifications provided by the City of Flagstaff Stormwater Section.
Base Course	The Base Course shall be AASHTO No. #3 or #4 coarse aggregate as called for in Figure 3.9. Assume 30 percent of total volume is open pore space. Unless an impermeable membrane liner is required in Item 8, at least 6-inches of the subgrade underlying the *Base Course* shall be sandy and gravely material with no more than 10% clay fraction.
Geotextile Fabric	Place a woven geotextile fabric at the bottom of the Base Course as shown in Figure 3.9. Use a geotextile material that meets the following requirements: ASTM D-4751 - AOS U.S. Std. Sieve #50 to #70 and D-4633 – Trapezoidal tear strength $\geq$ 100 x 60 lbs; COE specified minimum open area $\geq$ 4%
Geotextile Fabric or Impermeable Liner	When expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 16 mil thick, or heavier, liner on the bottom and sides of the basin under the pavement. If soils are not expansive (i.e., NRCS Type A, B or C), use a woven geotextile material that meets these requirements specified under item 5 above. Products that meet these requirements are: US Fabric US 2070 and US 670, Mirafi Filterweave 500 and 700, Carthage Mills Carthage 6%.
Geotextile Fabric & Membrane Installation	Place by rolling fabric parallel to the contours starting at the most downstream part of the pavement. Provide a minimum of 18-inches of overlap between adjacent sheets. Bring up geotextile and impermeable membrane to the top of perimeter walls. Attach membrane and fabric to perimeter walls with roofing tar or other adhesive or concrete anchors. Provide sufficient slack in the geotextile and membranes to prevent stretching them when sand and/or rock is placed. Seal all joints of impermeable membrane to be totally leak free.

Contained Cells - Lateral Flow Barriers	Install lateral-flow cut-off barriers using 16 mil, or thicker, PE or PVC membrane liner or concrete walls installed parallel to the contours (i.e., normal to the flow) to prevent flow of water downstream and then surfacing at the toe of the PP installation. Distance (L_{MAX}) between these cut-off barriers shall not exceed:

$$L_{MAX} = \frac{D}{1.5 \bullet S_O}$$

in which, L_{MAX} = Maximum distance between cut off membrane normal to the flow (ft),

S_O = Slope of the Base Course (ft/ft),

D = Depth of gravel *Base Course* (feet).

Subdrain System	When the PCP is located on NRCS Type D soils, when the Type B or C soil sub-base is to be compacted for structural reasons, or when an impermeable membrane liner is needed, install a subdrain system using Schedule 40 HDPE pipe. Locate each perforated pipe just upstream of the lateral-flow cut-off barrier. Do not exceed 20-foot spacing. Use a control orifice sized to drain the pore volume of empty each cell between 6-hours and 24-hours. Provide cleanouts at a minimum of every 100' and use long radius (or sweep) fittings to facilitate maintenance. Access for a vaccum truck should be provided to each cleanout.
Design Area Ratio	The design area ratio shall not exceed 2.0 (ratio = contributing impervious area divide by porous pavement area).

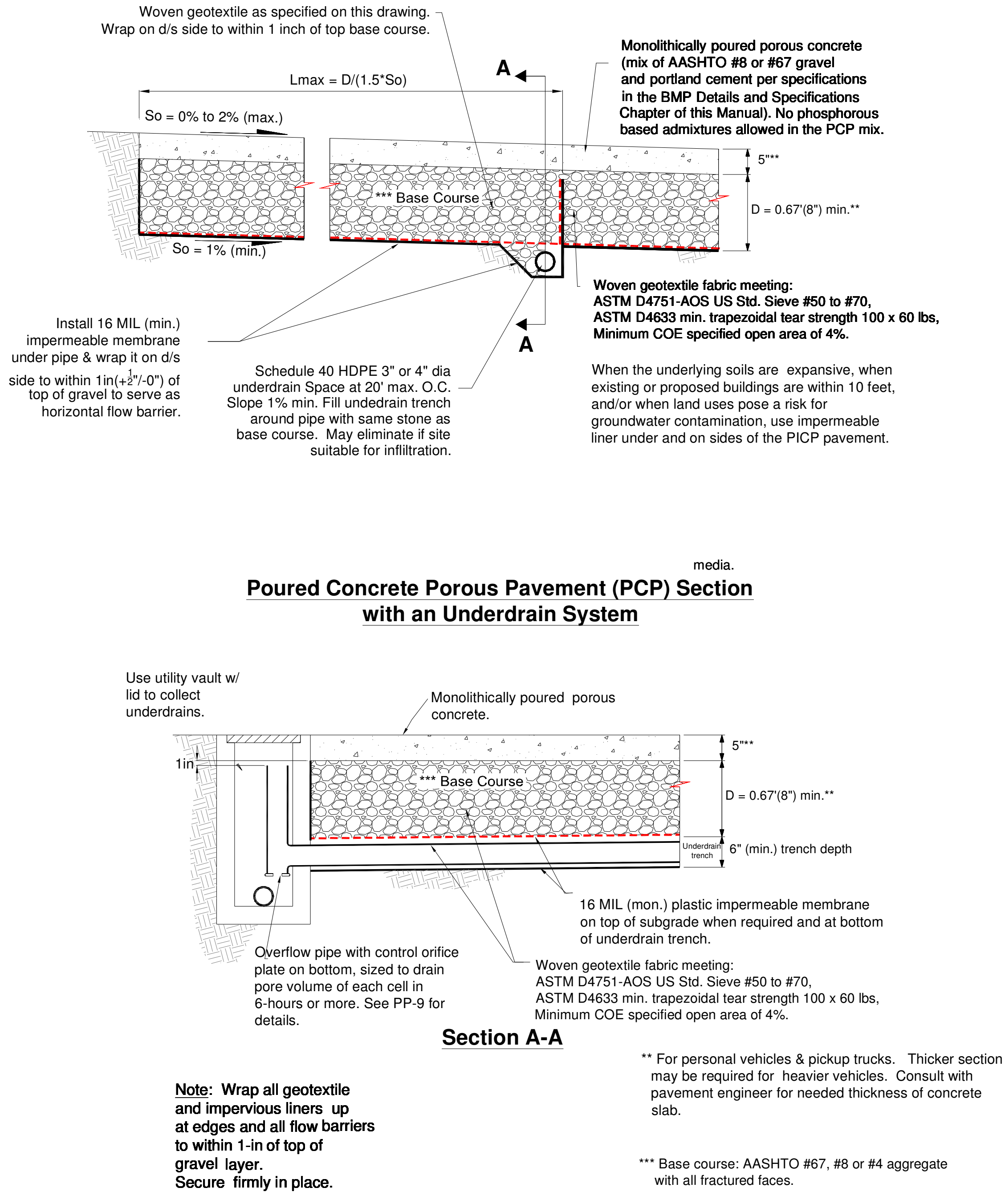


Figure 3.9 - Porous Concrete Pavement (PCP) – Typical Sections

3.5.5.5. Porous Asphalt (PA) Installations

Design Thickness

Design the thickness of the porous asphalt to have a finished thickness of 2.5 inches with a bituminous binder of 5.5% to 6.5% by weight dry aggregate.

Asphalt Binder

Use neat asphalt binder modified with an elastomeric polymer to produce a binder meeting the grading requirements of PG 76-22. The elastomeric polymer shall be styrene-butadiene-styrene (SBS) or approved equivalent, applied at a rate of 3% by total weight of the binder. The composite materials shall be thoroughly blended at the asphalt refinery or terminal prior to being loaded into the transport vehicle. The polymer modified asphalt binder shall be heat and storage stable. Acid modified binders shall not be accepted.

Aggregate Gradation

Unless otherwise approved by the Engineer, the aggregate in the asphalt mix shall be a minimum 90% crushed material and have the following gradation:

U.S. Standard Sieve Size	Percent Passing
0.5-inch (12.5 mm)	100
0.375-inch (9.5 mm)	75-95
# 4 (4.75 mm)	25-35
# 8 (2.36 mm)	10-15
# 16 (1.18 mm)	5-10
# 30 (600 μm)	1-5
# 200 (75 μm)	1-3

Batch Testing

To test draindown, air voids and abrasion, prepare three batches containing asphalt binder contents of 5.5, 6.0, and 6.5 percent by dry weight aggregate. The asphalt content that provides the best results according to the following table shall be selected as the final mix. Test the final mix for Moisture Susceptibility and Resistance to Stripping. If the final mix does not meet the requirements for Moisture Susceptibility and Resistance to Stripping, add hydrated lime until the requirements are met.

Asphalt Test	Requirement	Comments
Binder Downdrain (ASTM D 6390)	0.3% Maximum	Test at 15°C higher than production temperature
Air Voids of Compacted Mix	20% Minimum	Compact using 50 gyrations of Superpave gyratory compactor
Percent Weight Loss Test (Cantabro loss)	20% Maximum	Dry degradation and abrasion test for an unaged sample. DO NOT INCLUDE STEEL BALLS
Micro Deval Test (ASTM D6928- 08)	18% Maximum	Wet degradation and abrasion test
Moisture Susceptibility by the modified Lottman method (AASHTO T 283)	80% Minimum Tensile Strength Ratio (TSR)	Only required for final mix
Resistance to Stripping by Water (ASTM D 3625)	95% Minimum Coating Area	Only required for final mix

Choker Coarse Aggregate	The choker coarse aggregate shall be AASHTO No. 67, with all fractured faces. The choker coarse aggregate shall have a uniform thickness of 2.0 inches.
Base Coarse	The base coarse aggregate shall be AASHTO No. 3 with a uniform thickness of 7 inches. The base coarse aggregate shall rest on top of a 1 inch thick sand cushion layer IN ADDITION TO the required sand layer and on top of the Geotextile Fabric.
Sand Layer	The bottom sand layer shall be ASTM C-33 sand and will be installed under the base coarse and above the underdrain trench, when one is used, between two layers of Geotextile Fabric.
Geotextile Fabric	The Geotextile Fabric shall be installed below the sand cushion layer of the base coarse as well as below the bottom sand layer, as shown in Figure 3.5.
Geotextile Fabric or	When expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 16 mil thick, or

Impermeable Liner	heavier, liner on the bottom and sides of the basin under the pavement. If soils are not expansive (i.e., NRCS Type A, B or C), use a woven geotextile material.
Fabric and Liner Installation	Place fabric and liner by rolling parallel to the contours starting at the most downstream part of the pavement. Provide a minimum of 18 inches of overlap between adjacent sheets. Bring up Geotextile Fabric and impermeable liner to the top of the perimeter walls and attach with roofing tar or other adhesive or concrete anchors. Provide sufficient slack in the Geotextile Fabric and impermeable liner to prevent stretching during the installation of the infiltration bed, choker course and wearing course aggregate. Seal all joints of the impermeable liner to be totally leak free.
Contained Cells - Lateral Flow Barriers	Install lateral-flow cut-off barriers using 16 mil, or thicker, PE or PVC membrane liner or concrete walls installed parallel to the contours (i.e., normal to the flow) to prevent flow of water downstream and then surfacing at the toe of the PA installation. Distance (L_{MAX}) between these cut-off barriers shall not exceed: $$L_{MAX} = \frac{D}{1.5 \bullet S_O}$$ in which, L_{MAX} = Maximum distance between cut off membrane normal to the flow (ft), S_O = Slope of the Base Course (ft/ft), D = Depth of gravel *Base Course* (feet).
Subdrain System	When the PA is located on NRCS Type D soils, when the Type B or C soil sub-base is to be compacted for structural reasons, when infiltration rates are less than 1.0 in/hr, or when an impermeable membrane liner is needed, install a subdrain system using Schedule 40 HDPE pipe. Locate each perforated pipe just upstream of the lateral-flow cut-off barrier. Do not exceed 20-foot spacing. Use a control orifice sized to drain the pore volume of empty each cell between 6-hours and 24-hours. Provide cleanouts at a minimum of every 100’ and use long radius (or sweep) fittings to facilitate maintenance. Access for a vaccum truck should be provided to each cleanout.
Design Area Ratio	The design area ratio shall not exceed 2.0 (ratio = contributing impervious area divide by porous pavement area).

3.5.5.6. Porous Gravel Pavement (PGP) Installations.

Design RPGP Thickness

Design the thickness of the porous gravel layer to support the traffic and vehicle types the pavement will have to carry.

Gravel Base Course

Provide the required Base Course of AASHTO No. 67 or ASTM No. 57 coarse as called for in the detail drawing. The aggregate shall have all fractured surfaces as called for in Figure 3.10. Assume 30 percent of total volume is open pore space.

Unless an impermeable membrane liner is required in Item 6, at least 6-inches of the subgrade underlying the Base Course shall be sandy and gravely material with no more than 10% clay fraction.

Geotextile Fabric

Place a woven geotextile fabric on top of the Base Course as shown in Figure 3.10. Use a geotextile material that meets the following requirements:

ASTM D-4751 - AOS U.S. Std. Sieve #50 to #70 and D-4633 – Trapezoidal tear strength $\geq$ 100 x 60 lbs; COE specified minimum open area $\geq$ 4%

No additional geotextile fabric is required if it is included as part of the reinforcing gird.

Geotextile Fabric or Impermeable Liner Under the Base Course

When expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 16 mil thick, or heavier, liner on the bottom and sides of the basin under the pavement.

If soils are not expansive (i.e., NRCS Type A, B or C), use a woven geotextile material that meets these requirements specified under item 5 above. Products that meet these requirements are: US Fabric US 2070 and US 670, Mirafi Filterweave 500 and 700, Carthage Mills Carthage 6%.

Geotextile Fabric & Membrane Installation

Place by rolling fabric parallel to the contours starting at the most downstream part of the pavement. Provide a minimum of 18-inches of overlap between adjacent sheets.

Bring up geotextile and impermeable membrane to the top of perimeter walls. Attach membrane and fabric to perimeter walls with roofing tar or other adhesive or concrete anchors. Provide sufficient slack in the geotextile and membranes to prevent stretching them when sand and/or rock is placed. Seal all joints of impermeable membrane to be totally leak free.

Contained Cells - Lateral Flow Barriers

Install lateral-flow cut-off barriers using 16 mil, or thicker, PE or PVC membrane liner or concrete walls installed parallel to the contours (i.e., normal to the flow) to prevent flow of water downstream and then surfacing at the toe of the PP installation. Distance (L_{MAX}) between these cut-off barriers shall not exceed:

$$L_{MAX} = \frac{D}{1.5 \bullet S_O}$$

in which, L_{MAX} = Maximum distance between cut off membrane normal to the flow (ft),

S_O = Slope of the Base Course (ft/ft),

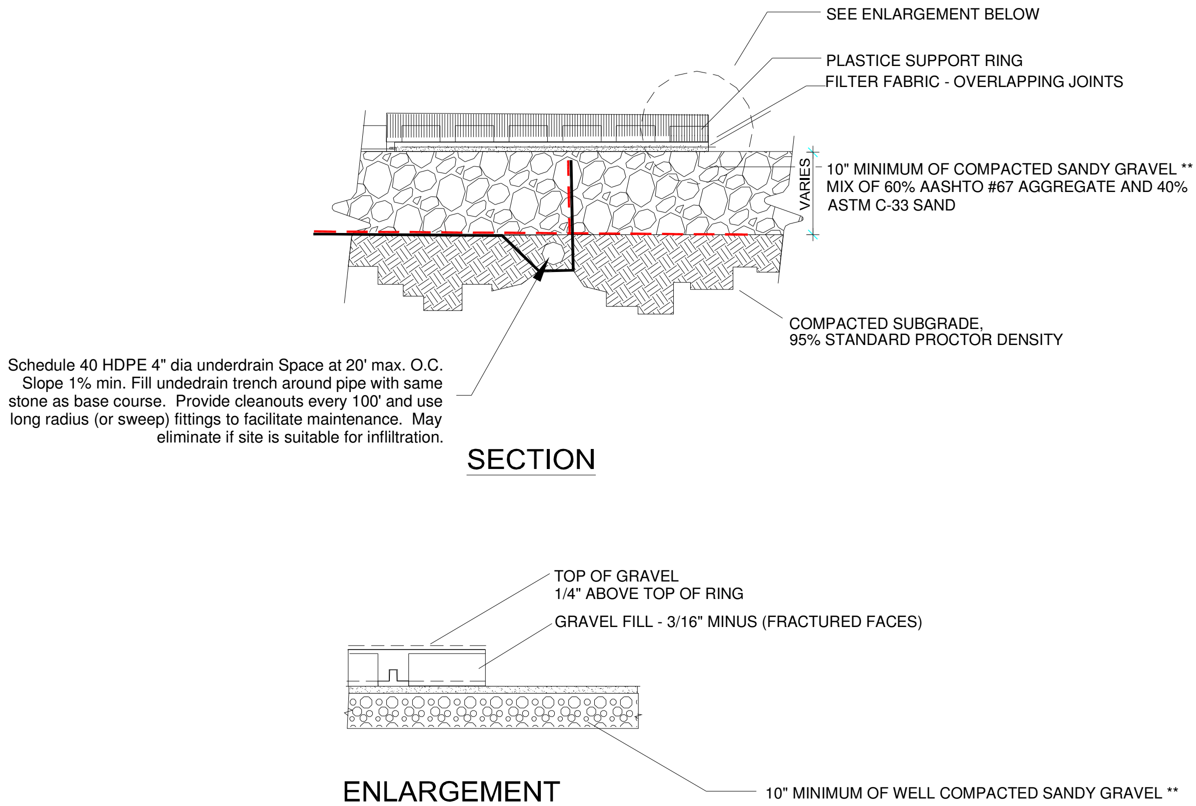
D = Depth of gravel Base Course (ft).

Subdrain System

When the RPGP is located on NRCS Type D soils, when the Type B or C soil sub-base is to be compacted for structural reasons, or when an impermeable membrane liner is needed, install a subdrain system using Schedule 40 HDPE pipe. Locate each perforated pipe just upstream of the lateral-flow cut-off barrier. Do not exceed 20-foot spacing. Use a control orifice sized to drain the pore volume of empty each cell between 6-hours and 24-hours. Provide cleanouts at a minimum of every 100' and use long radius (or sweep) fittings to facilitate maintenance. Access for a vaccum truck should be provided to each cleanout.

Design Area Ratio

The design area ratio shall not exceed 2.0 (ratio = contributing impervious area divide by porous pavement area).



NOTES:

1. INSTALL GRAVEL REINFORCING LAYER PER MANUFACTURER'S RECOMMENDATIONS INCLUDE MODIFICATIONS SHOWN ON THIS DRAWING.

2. DETAIL BASED ON INVISIBLE STRUCTURES, INC., ET AL DETAILS, BUT MODIFIED TO SUIT COF REQUIREMENTS.

** GREATER DEPTH OF PAVEMENT MAY BE REQUIRED BY PAVEMENT DESIGNER

Figure 3.10 – Reinforced Porous Gravel Pavement (PGP) – Typical Section

3.5.6. Construction Phase

The construction phase is very critical in having a successful porous pavement (PP) installation that is structurally sound, and has good rates of stormwater infiltration into the surface of the pavement and into the underlying sub-base or underdrains. It is not sufficient to use the same construction practices for PP as for conventional, non-porous pavement. Issues of concern are excessive compaction of the subgrade and heavy equipment traffic over these surfaces, proper gradation and installation of the gravel and sand materials at various levels of the PP section, proper use and installation of geotextile and impermeable liner membranes, edge restraints for modular block types of PP, transport and pouring of porous concrete mixes, achieving uniform gradation of gravels and soils for reinforced turf type of pavements and other issues that can affect the eventual performance of the PP.

3.5.6.1. Preparation and Compaction of the Sub-base

When the native soils in the subgrade are suitable for infiltration (i.e., NRCS Hydrologic Group A, B and C), it is important maintain their infiltration capacities as much as possible. When the sub-base is deliberately compacted to provide greater pavement stability or is inadvertently compacted by construction equipment traffic over them, infiltration capacity will be significantly reduced. To prevent the latter, it is crucial that heavy construction equipment, especially rubber-tired machinery, be kept off the sub-base. This will require the use of light track equipment, delivery of gravels via conveyors, delivery of concrete via extended chutes (not conveyors) or lift pour buckets, and stopping all work when the sub-base is wet or thawing.

When compaction of the sub-base is needed for structural support of the pavement that will carry or park vehicular traffic, an underdrain system may be needed to compensate for the loss of infiltration capacity. This will be the case if the sub-base soils have significant fractions of silt or clay and are not granular in nature (e.g., not Type A or B). Use the recommended PP sections with underdrains where they are recommended in the figures shown in this section of the *Manual*.

Compaction of the sub-grade is recommended for sites where the pavement will be placed on top of fill. Unless the fill is composed of predominantly granular materials, the engineer needs to plan for underdrains for all PP types.

3.5.6.2. Preventing Clogging of Porous Pavement by Excess Sediment Loads

It is common to install pavement before all site work such as landscaping and finishing of buildings is completed. As a result, sediment loads from construction and landscaping activities after the PP is installed can be very high. It crucial to protect all surfaces of the PP from runoff and sediment deposits until all construction activities are completed and the areas tributary to the PP are fully stabilized.

Regardless of the type of PP being used, the highest priority during construction has to be to prevent sediment from entering the *Base Course* and the surface of PP. The following practices will help to keep the PP form being clogged during these construction periods:

- Keep muddy equipment and materials away from the PP area
- Install silt fences and temporary swales to divert water away from the PP area
- Cover the surfaces with heavy flexible impermeable membrane whenever construction activities threaten to deposit sediment onto the PP area

3.5.6.3. Geotextile Installation

The types of geotextile fabric that are considered minimum for PPs are recommended in this section of the *Manual*. High quality fabrics need to be used that resist puncturing by angular rock and during installation. After any layer of the fabric is laid down, it shall be inspected for proper overlaps, tears, punctures and contamination by oils, greases, or mud. If any tears or punctures are found, or the overlaps do not meet the minimums specified, or the material is contaminated, the defective materials shall be replaced.

3.5.6.4. Base Course and Sand Layer Installation

Regardless of the PP type being used, if a granular Base Course is called for, install the crushed aggregate on top of the geotextile fabric that was laid down over the sub-base. Each lift shall not exceed 6-inches and shall be compacted by using a 10-ton, or heavier, vibrating steel drum roller. Make at least four passes with the roller, with the initial passes made while vibrating the roller and the final one to two passes without vibration.

After all the lifts are compacted, the specified geotextile fabric shall be laid down on top of the compacted aggregate and the sand, or soil, materials spread on top. The sand, or soil, material shall be compacted using at least four passes of the 10 ton steel drum static roller. Then lay down the specified geotextile fabric top of the sand as called for in the plans.

If the design calls for an upper layer of the Base Course, install it using the same layer thicknesses and compaction requirements described above. Follow-up the installation of the uppermost layer of the Base Course by installing the specified geotextile fabric on top of it. The leveling course or porous pavement, as required by the plans, is then applied over the uppermost geotextile fabric.

When a sand leveling course is called for in the plans, compact it using the drum roller before laying the paver units on top of it. If the top of the Base Course or the leveling course layers are disturbed and not uniform, they shall be releveled and recompacted. The top of each layer below the leveling course shall be uniform and will not deviate more than $\pm$1/2-inch when a 10 foot straight edge is laid on it surface. The top of the leveling course shall not deviate more than $\pm$3/8-inch in 10 feet.

3.5.6.5. MBP and PICP Paver Installation

Place the paver blocks tightly against each other on top of the compacted aggregate leveling course. Before compacting the pavers into place, cut and place paver units to tightly fill spaces between adjacent pavers and the restraining wall at the edges.

Compact the installed paver blocks initially using a plate compactor that exerts a minimum of 5,000 lbs/ft^2 when using 4-inch thick pavers and a minimum of 6,800 lbs/ft^{2}when using pavers thicker than 4-inches. After initial compaction, fill the paver openings and joints to the top with aggregate or sand and compact again. If the sand or gravel infill drops more than 1/8 inch below the top of the paver block, add more sand and recompact. Remove excess sand or gravel by broom sweeping the surfaces. Paver installation can be done by hand or using mechanical equipment specially designed for this type of work. If the latter is used, follow the requirements and procedures provided in the ICPT(1998) *Technical Specification 11 – Mechanized Installation of Interlocking Concrete Pavements*.

3.5.6.6. PCP Installation

Pour the porous concrete mix directly on the compacted *Base Course*. It is critical to keep the residence time of the mix in the delivery truck to less than one-hour after the water was added to the mix. It is also critical that no additional water be added after it is first introduced into the mix to make the concrete "more workable". Asphalt laying equipment or hand working of the mix has been used successfully to lay down the pavement, flowed with a light reverse turning roller compaction to settle the aggregate into place. Do not use vibrators to work the concrete as these will cause the cement to separate from the aggregate and flow to the bottom of the pavement. Extended delivery times, especially in warm weather, and adding more water after water has been introduced into the concrete mix weakens the cementatious bond between the individual aggregate stones and result in premature pavement unraveling, potholing and other failures. The use of water reducing agents and viscosity modifiers have helped to keep the cement/water ratio low while having good workability of the mix.

It is also critical that concrete trucks do not drive over the sub-base and the compacted *Base Course* in areas where PCP is to be installed. Use extended chutes or bucket dumpers with a crane or small tracked front-end loaders to deposit concrete. Closely follow the placement, compaction and finishing instruction in the sample specifications provided in the TYPICAL STRUCTURAL IMP SPECIFICATIONS chapter of this *Manual*.

3.5.6.7. PA Installation

The Owner shall be notified at least 24 hours prior to any installation, including all infiltration bed stages and the placing of the porous asphalt. On the day the porous asphalt is to be placed, the ambient temperature must be 55 degrees Fahrenheit or greater. The porous asphalt shall be transported to the site in vehicles with smooth, clean dump beds that have been sprayed with a non-petroleum release agent and shall be covered to prevent cooling. The porous asphalt shall not be stored in excess of 90 minutes before placement. The surface shall be placed in one lift, directly over the choker course aggregate. The laying temperature must be between 300 degrees and 350 degrees Fahrenheit. The use of a remixing material transfer device between the trucks and the paver is highly recommended to eliminate cold lumps in the mix.

A well heated screed should be used to minimize the need for raking, as the polymer-modified asphalt is very difficult to rake. Compaction of the surface (HMA) shall take place when the surface is cool enough to resist a 10-ton roller. One or two passes is all that is required for proper compaction, as additional rolling will reduce surface porosity. After the final rolling, no vehicular traffic of any kind shall be allowed on the surface until cooling and hardening has taken place, and in no case in the first 48 hours. Any striping paint that is to be used for parking lanes or lanes of traffic shall be chlorinated rubber base, factory mixed, non-bleeding, fast drying, with a life expectancy of at least 2 years under normal traffic usage.

The porous asphalt shall be inspected at least 4 times during the first 3 months to verify the surface smoothness and uniform drainage. Therefore it is recommended that inspections take place during storm events (if possible) to verify infiltration as well as the minimization of pooling and runoff, and to identify any potential clogging. Additional inspections shall also take place after large storm events and on an annual basis. If any potholes or cracks are noticed, these areas can be patched using standard patch mixes as long as the impervious area does not exceed 10% of the total porous asphalt area.

General maintenance shall include vacuum sweeping approximately 4 times a year, depending on usage, followed by high pressure hosing to free the pores in the top layer from clogging. Annual inspections are recommended for surface deterioration or spalling.

3.5.6.8. RGP Installation

For the *Reinforced Grass* type of installations adhere strictly to the recommendations of the manufacturer for the installation of this pavement.

3.5.6.9. RPGP Installation

Follow the recommendations in Section 3.5.6.4 above for the *Base Course* and adhere to the recommendations of the manufacturer for the installation of this pavement.

3.6. POROUS PAVEMENT DETENTION (PPD)

3.6.1. Description

Porous pavement detention (PPD) consists of an installation of MBP that is flat (i.e., S_o=0.00% in all directions) and is provided with a 0.3 foot (3.6") deep surcharge zone to temporarily store the ROCV draining from an adjacent drainage area. Runoff will infiltrate into the void spaces of the gravel Base Course through the sand and sandy loam turf. The latter is not used for the PPD facility to insure more rapid drainage of the parking surface and easy maintenance when the media needs to be replaced to maintain rapid drainage of the ponding areas. The ponded and filtered water slowly exits through an underdrain.

3.6.2. General Application

PPD may be used in the same types of low vehicle movement zones identified in Section 3.5 Porous Pavements for MBP with the driveways leading up to them being solid pavement.

3.6.3. Advantages/Disadvantages

PPD has generally the same advantages and disadvantages as MBP. Its additional advantage is to provide a means to provide *ROCV* for a site that has little available open area for detention.

3.6.4. Design Considerations

Figure 3.11 shows a cross-section of modular block installation and its subgrade for PPD.

3.6.5. Design Procedure and Criteria

The following steps outline the PPD design procedure and criteria.

1. Basin Storage Volume

   Calculate the Design Volume in cubic-feet as follows:

   1. $$Design\ Volume = \left(\frac{1''\,rain}{12}\right) * Area$$

   2. In which: *Area* = the impervious portion of the watershed area tributary to the PPD (square feet), including the PPD area.

2. Surface Area Minimum surface area (ft^2) = $\dfrac{\text{Design Volume (ft}^3)}{0.17 \text{ feet}}$

3. Select Block Select appropriate modular blocks that have **no less than 40 percent of the surface area open**. The manufacturer's installation requirements shall be followed with the exception that *Rock Media Pore Volume Inlay Material* and *Base Course* dimension and

		requirements of this section shall be adhered with.
4.	Select Porous Pavement Infill	The MBP openings should be filled with ASTM C-33 graded sand (fine concrete aggregate) and not sandy loam turf. Place a 1-inch layer of sand leveling-course below the blocks. The use of locally available recycled glass is also acceptable if the designer proposes it.
5.	Base Course	The Base Course shall be AASHTO # 3, #4, or #67 coarse aggregate; all fractured surfaces. For pore volume estimates assume 30 percent of the total volume to be open pore space. When an underdrain is not provided, at least 6-inches of the subgrade underlying the Base Course shall be sandy and gravely material with no more than 10% clay fraction.
6.	Perimeter Wall	Provide a concrete perimeter wall to confine the edges of the PPD area. The wall should be minimum 6-inch wide and at least 12 inches deeper than all the porous media and modular block depth combined.
7.	Geotextile Fabric on Top of the Base Course	Place a woven geotextile fabric over the Base Course as shown in Figure 3.11
8.	Geotextile Fabric or Impermeable Liner Under the Base Course	When expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 16 mil thick, or heavier, liner on the bottom and sides of the basin under the pavement. If soils are not expansive (i.e., NRCS Type A, B or C), use a woven geotextile material
9.	Geotextile Fabric & Membrane Installation	Place by rolling fabric parallel to the contours starting at the most downstream part of the pavement. Provide a minimum of 18-inches of overlap between adjacent sheets. Bring up geotextile and impermeable membrane to the top of perimeter walls. Attach membrane and fabric to perimeter walls with roofing tar or other adhesive or concrete anchors. Provide sufficient slack in the geotextile and membranes to prevent stretching them when sand and/or rock is placed. Seal all joints of impermeable membrane to be totally leak free.
10.	Subdrain System	When the PPD is located on NRCS Type D soils, when the Type B or C soil sub-base is to be compacted for structural reasons, or when an impermeable membrane liner is needed, install a subdrain system using Schedule 40 HDPE pipe, not exceeding 20-foot spacing between pipes. Use a control orifice sized to drain the pore volume to empty each cell between 6 and 24-hours. Provide

cleanouts every 100' or less, and use long radius (or sweep) fittings to facilitate maintenance. Access for a vaccum truck should be provided to each cleanout.

11. Design Area Ratio — The design area ratio shall not exceed 2.0 (ratio = contributing impervious area divided by porous pavement detention area).

12. Overflow — Provide an overflow with an inlet to a storm sewer, set at 2 inches (-0, + ½-inch) above the level of the porous pavement surface. Make sure the 2-inch ponding depth is contained and does not flow out of the area at ends or sides until the 2-inch ponding depth is reached.

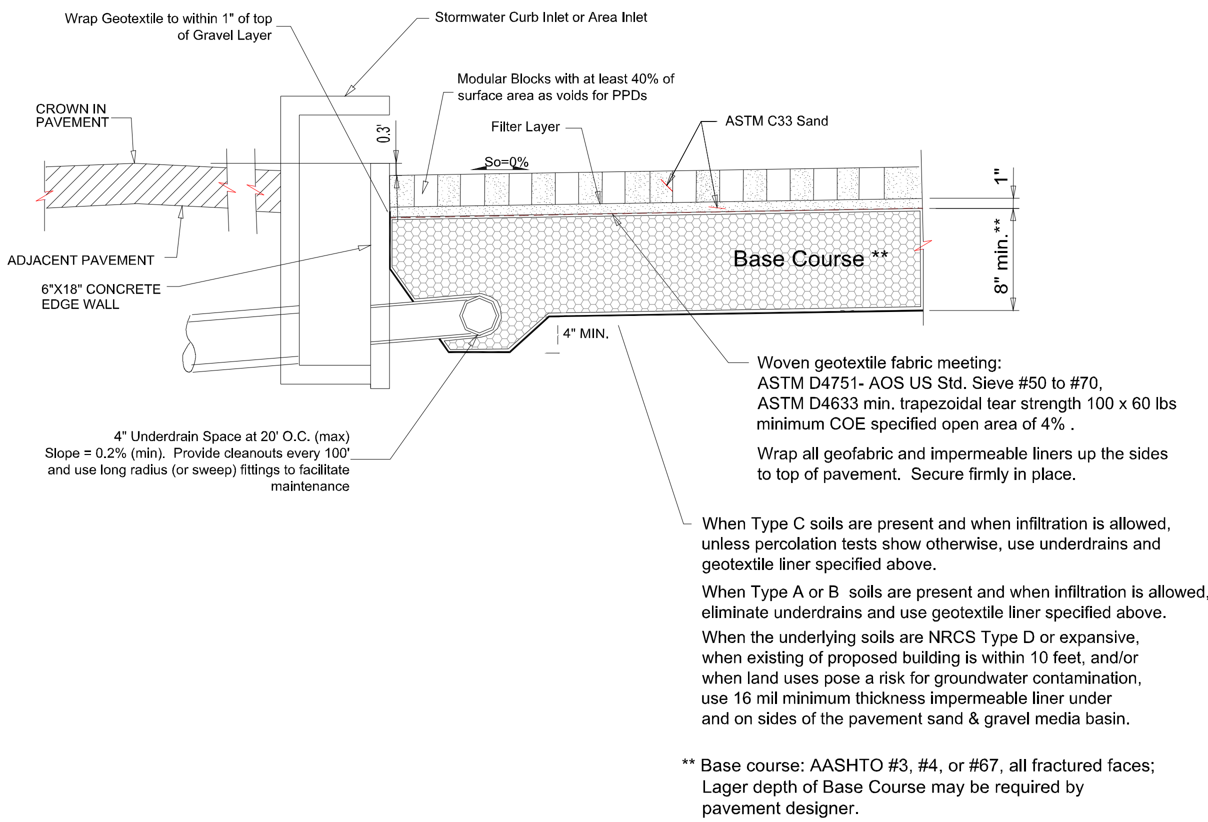


Figure 3.11 - Porous Pavement Detention (PPD) – Typical Section

3.7. BIO-RETENTION (BR)

3.7.1. Description

Bio-Retention (BR) consists of a low-lying vegetated area underlain by a sand/soil bed and gravel/underdrain system. A shallow surcharge zone exists above the BR for temporary storage of the ROCV. During a storm, accumulated runoff ponds in the vegetated zone and infiltrates into the underlying sand/soil bed, filling the void spaces of the sand. The underdrain gradually dewaters the sand/soil bed and discharges the runoff to a nearby channel, swale, or storm sewer. Like PPD, this IMP allows the ROCV to be provided on a site that has little open area available for stormwater detention.

3.7.2. General Application

3.7.2.1. Locating

A BR cell can be located in just about any of the open areas of a site. It is ideally suited for small installations such as:

- Parking lot islands
- Street medians
- Roadside swale features
- Site entrance or buffer features

However, this IMP may also be implemented at a larger scale, serving as an infiltration basin for an entire site if desired, provided the runoff capture volume and average depth requirements contained in this section are met.

3.7.2.2. Example Application

The following photos illustrate an installation of Bio-Retention cell at a dealership at the Flagstaff Automall..

Excavation showing drain rock, geotextile fabric liner, and underdrains.

Completed BR facility with plantings and surface storage volume shown. Runoff from the parking areas enter through curb cuts.

3.7.3. Advantages/Disadvantages

3.7.3.1. General

A primary advantage of BR is making it possible to provide *ROCV* on a site while reducing the impact on developable land. A BR provides a natural moisture source for vegetation, enabling "green areas" to exist without irrigation.

The primary disadvantage of BR is a potential for clogging if a moderate to high level of silts and clays are allowed to flow into the facility. Also, this IMP should not be placed close to building foundations or other areas when expansive soils are present, although an underdrain and impermeable liner can ameliorate some of this concern.

3.7.3.2. Physical Site Suitability

If an underdrain system is incorporated into this IMP, BR is suited for about any site regardless of in-situ soil type. If sandy soils are present, the facility can be installed without an underdrain (infiltration option); granular subsoils are not a requirement. This IMP has a flat surface area, and may be more difficult to incorporate it into steeply sloping terrain.

3.7.4. Design Considerations

Figure 3.12 shows a cross-section for a BR cell. When implemented using multiple small installations on a site, it is increasingly important to accurately account for each upstream drainage area tributary to each BR site to make sure that each facility is properly sized, individual BR sites intercept runoff from their respective tributary areas, and that all portions of the development site are directed to a BR.

The designer needs to decide early on if infiltration is possible or allowed at the BR site as that will affect the design cross-section and whether underdrains will be needed. Considerable savings can be achieved if the site is suitable for infiltration, sites that typically have NRCS Soil

Types A, B or C. The best way to determine if the site is suitable for BRs without underdrains is to perform a standard individual septic disposal system percolation test at a depth equal to the bottom of the BR. The test shall be performed or supervised by a licensed professional engineer. If the engineer certifies that the site has a percolation rate of greater than 1 inch per hour, underdrains and the supporting gravel layers may be eliminated.

3.7.5. Design Procedure

The following steps outline the BR design procedure and criteria.

1. Basin Storage Volume

B. Calculate the Design Volume in cubic feet as follows:

$$Design\ Volume = \left(\frac{1''\ Rain}{12}\right) * Area$$

In which:

Area = The impervious watershed area tributary to the Bio-retention (square feet).

2. Surface Area and Maximum ROCV Depth

Calculate the minimum required **flat** surface area of the BR as follows:

$$\text{Flat Surface Area} = \frac{\text{Design Volume in ft}^3}{d}$$

in which,

d = ROCV depth (9" ideal, 12" maximum) of the BR basin, ft.

3. Sand/Peat Media

Provide, as a minimum, an 18-inch layer of well mixed planting media as shown in Figure 3.12. Typically the planting media consists of a mixture of sand and an organic material such as peat, top soil, mulch, or compost. Consult the City of Flagstaff Stormwater Section for planting media specifications.

Maintain top surface flat. If sideslopes need to be steeper than 3h:1v (4h:1v or flatter preferred), use vertical walls. Planting media shall be delivered fully mixed in a drum mixer. On-site mixing of piles shall not be allowed.

4. Granular Subbase and Underdrains

Granular material shall have all fractured faces such as AASHTO #3, #4, or #67. The use of locally available black clinkers (leach cinders) is also acceptable if the designer proposes it.

Install a subdrain system using Schedule 40 HDPE pipe, not exceeding 20-foot spacing between pipes. Use a control orifice sized to drain the pore volume to empty each cell between 6 and 36-hours. Provide cleanouts every 100' or less, and use long radius (or sweep) fittings to facilitate maintenance. Access for a vaccum truck should be provided to each cleanout.

5. Impermeable

When the underlying soils are expansive, when existing or proposed building

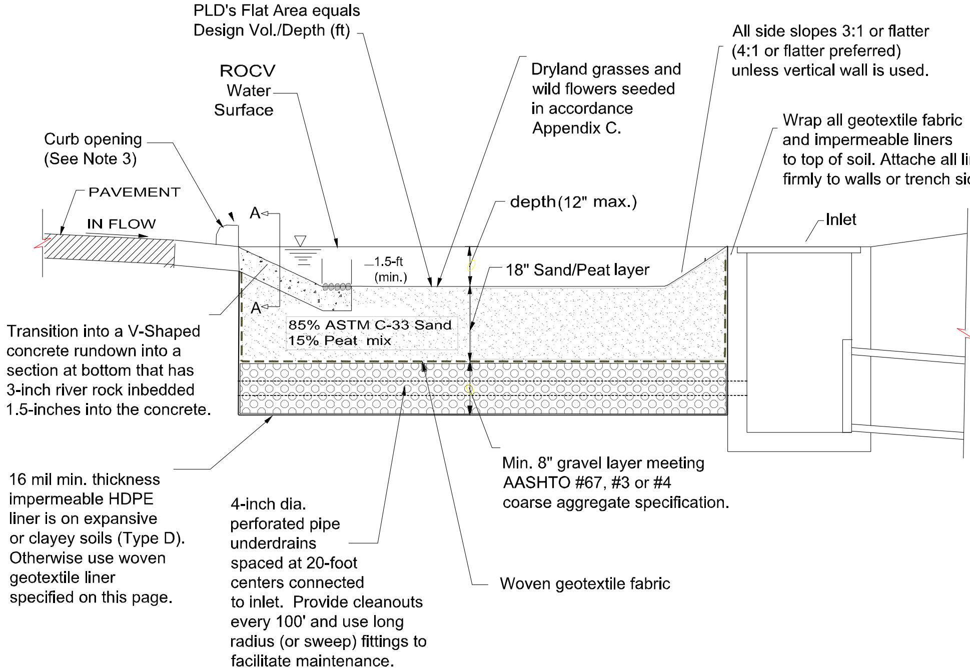
Membrane and Geotextile Liners	is within 10 feet, and/or when land uses pose a risk for groundwater contamination, install an impermeable 16 mil thick, or heavier liner under and on sides of the Bio-retention basin. If soils are not expansive, use a woven geotextile material Wrap all liners to top of the BR basin and attach firmly with staples to the soil vertical wall using staples or concrete anchors. Provide sufficient slack so that the liners are not stretched when rock and soil are placed. If tears are seen or discovered, repair them as recommended by manufacturer with no less than 18 inches of overlap on all sides of the tear.

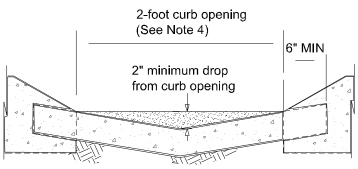
3.7.6. Vegetating the BR Surface

It is recommended the BR's infiltrating surface be vegetated with drought tolerant native and low water use grass species that do well in sandy soils. The City of Flagstaff Stormwater Section maintains a list of acceptable seed mixes and planting procedures that should be followed.

Do not use shrubs or trees in the flat surface of the BR. Their roots can damage geotextile liners and will interfere with regular and restorative maintenance. If used on sideslopes, locate them at least 6 inches above the flat surface and have the geotextile and/or impermeable liners placed between them and the flat BR surface. DO NOT USE SOD. It will seal the BR's surface and destroy its infiltration capacity. If the BR surfaces will be irrigated, do not place sprinkler heads on the flat surface.

First year maintenance needed to establish good growth should include temporary irrigation and mowing to control annual weeds. Mowers should be rotary and the tractor small enough not to rut the soil and damage the vegetation. If needed, spot treat with approved herbicides to control noxious weeds. Reseed bare areas after the first growing season.





3-feet wide 2-inch deep V-pan
Imbed a 6-inch layer of 3-inch river rock
into the soil for one foot on each side of
the pan if a 2 foot curb opening is used.
SECTION A-A

Notes:

(1) This detail is provided to illustrate one acceptable way to introduce runoff into the BR and provide an overflow, and is not intended to constrain the designer to this configuration.

(2) When the underlying soils are expansive, when existing or proposed building is within 10 feet, and/or when land uses pose a risk for groundwater contamination, use impermeable liner under and on sides of the Bio-retention basin.

(3) Provide a minimum of a 1- to 2-foot wide curb opening every 10 feet (20 feet for 2-wide opening) of curb.

Figure 3.12 - Bio-Retention – Typical Sections

3.8. EXTENDED DETENTION BASIN (EDB)—SEDIMENTATION FACILITY

3.8.1. Description

An extended detention basin (EDB) is a sedimentation basin designed to totally drain dry at least 36 hours after stormwater runoff ends. It is an adaptation of a detention basin used for flood control. It is a stormwater filter that consists of a runoff storage zone underlain by a sand/soil bed and gravel storage zone with an underdrain system. During a storm, accumulated runoff ponds in the surcharge zone and gradually infiltrates into the underlying sand/soil bed and gravel storage zone, filling the void spaces. The underdrain gradually dewaters the sand/soil bed and gravel storage zone and discharges the runoff to a nearby channel, swale, or storm sewer.

The EDB's drain time for the brim-full runoff capture volume (i.e., time to fully evacuate the design ROCV) of between 24 and 36 hours is recommended to remove a significant portion of fine particulate pollutants found in urban stormwater runoff. The basins are considered to be "dry" because they are not designed to have a permanent pool of water remaining between storm runoff events. However, EDB may develop wetland vegetation and sometimes shallow pools in the bottom portions of the facilities.

Because the bottom will be the depository of all the sediment that settles out in the basin, the bottom can be muddy and may have an undesirable appearance to some. To reduce this problem, and to improve the basin's availability for other uses (such as open space habitat and passive recreation), a sediment trap and underdrain system are incorporated into the EDB design. This provides an opportunity for larger particles to settle out in the inlet in an area that has a solid surface bottom to facilitate mechanical sediment removal and ensures ponded water drains within a short time.

3.8.2. General Application

An EDB is generally suited to onsite configurations where there is no base flow and is put in operation when the upstream catchment no longer has construction or grading/landscaping activities. The EBD can be used to enhance stormwater runoff quality and reduce peak stormwater runoff rates. Also, an EDB can sometimes be retrofitted into existing flood control detention basins.

EDBs can be used to improve the quality of urban runoff coming from roads, parking lots, residential neighborhoods, commercial areas, and industrial sites and are generally used for regional or follow-up treatment. EDBs are most applicable for catchments with a tributary impervious area of 10 acres or more. They can be used as an onsite IMP that works well with other IMPs, such as upstream onsite source controls. A flood routing detention volume for the 10 and 100 year storm events, per the City of Flagstaff *Stormwater Management Design Manual*, may be provided above the runoff capture volume (*ROCV*) of the basin.

3.8.3. Advantages/Disadvantages

3.8.3.1. General

Primary advantages of SFBs include effective water quality enhancement through settling and filtering. The primary disadvantage is a potential for clogging if a moderate to high level of silts and clays are allowed to flow into the facility. **For this reason, the EDB should not be put into operation while construction or major landscaping activities are taking place in the tributary catchment.** Also, this IMP should not be located close to building foundations or other areas where expansive soils are a concern, although an underdrain and impermeable liner can ameliorate some of this concern.

An EDB can be designed to provide other benefits such as recreation and open space opportunities in addition to reducing peak runoff rates and improving water quality. They are effective in removing particulate matter and the associated heavy metals and other pollutants. As with other IMPs, safety issues need to be addressed through proper design.

3.8.3.2. Physical Site Suitability

Since an underdrain system is incorporated into this IMP, SFB is suited for about any site; presence of sandy subsoils is not a requirement. This IMP has a flat surface area, so it may be more challenging to incorporate it into steeply sloping terrain.

3.8.3.3. Maintenance Needs

Before selecting this IMP, be sure that the minimal maintenance specified in the MAINTENANCE RECOMMENDATIONS chapter of this *Manual* will be provided by either a Home Owner's Association or by the owner. This IMP's performance is dependent on having regular maintenance provided.

3.8.4. Design Considerations

The design of all detention facilities shall be in accordance with Chapter 8 of the City of Flagstaff *Stormwater Management Design Manual*. Whenever possible try to accommodate within the basin other urban uses such as passive recreation and wildlife habitat. Generally, the area within the *ROCV* is not well suited for active recreation facilities such as ballparks, playing fields, and picnic areas. These are best located above the *ROCV* pool level.

Although the soil types beneath the pond seldom prevent the use of this IMP, they should be considered during design. Any potential exfiltration capacity should be considered a short-term characteristic and ignored in the design of the *ROCV* because exfiltration will decrease over time as the soils clog with fine sediment. Stable, all weather access to critical elements of the pond, such as the inlet, outlet, spillway, and sediment collection areas must be provided for maintenance purposes.

3.8.5. Design Procedure and Criteria

The following steps outline the design procedure and criteria for an EDB.

Basin Storage Volume

Provide a storage volume equal to 100 percent of the *ROCV* based on a 36-hour drain time, above the bottom of the basin.

Calculate the Design Volume in acre-feet as follows:

$$Design\ Volume = \left(\frac{1"\, Rain}{12} \right) * Area$$

In which:

Area = The impervious watershed area tributary to the extended detention pond

Outlet Works

The outlet works consists of 4” perforated HDPE pipe to convey water to the overflow outlet structure. Space perforated pipe on 20 foot centers or less. At the outlet of the HDPE pipe into the box, install an orifice sized to empty the ROCV above the sand/soil layer in no less than 24 hours and no more than 36 hours.

Provide an overflow outlet pipe out of the overflow structure to convey flows when the runoff volume exceeds the ROCV at rates required by Chapter 8 of the City of Flagstaff *Stormwater Management Design Manual*

Trash Rack

Provide a trash rack of sufficient size to prevent clogging of the primary water quality outlet. Size the rack so as not to interfere with the hydraulic capacity of the outlet. See Chapter 8 of the City of Flagstaff *Stormwater Management Design Manual*

Basin Shape

Shape the pond whenever possible with a gradual expansion from the inlet and a gradual contraction toward the outlet, thereby minimizing short circuiting. To achieve this, it may be necessary to modify the inlet and outlet points through the use of pipes, swales or channels.

Always maximize the distance between the inlet and the outlet.

Basin Side Slopes

Basin side slopes should be stable and gentle to facilitate maintenance and access. Side slopes should be no steeper than 4:1 and the use of flatter slopes is recommended; the flatter, the better and safer.

Vegetation

Bottom vegetation provides erosion control and sediment entrapment. Pond bottom, berms, and side sloping areas may be planted with native and low water use grasses, depending on the local setting and needs. The City of Flagstaff Stormwater Section maintains a list of acceptable seed mixes and planting procedures that should be adhered to.

Access

All weather stable access to the bottom, sediment trap, and outlet works area shall be provided for maintenance vehicles. Grades should not exceed 10 percent, and a solid driving surface of gravel, rock, concrete, gravel-stabilized turf, riprap should be provided.

Sediment Trap Design

Sediment trap provides an opportunity for larger particles to settle out in the inlet in an area that has a solid surface bottom to facilitate mechanical sediment removal. A rock berm or concrete-wall should be constructed between the Sediment Trap and the main EDB. The sediment trap volume should be about 3 to 5 percent of the design *ROCV*. A pipe through the berm to convey water to the main body of the EDB should be offset from the inflow streamline to prevent short circuiting and should be sized to drain the Sediment Trap volume in 3 to 5 minutes, respectively. The floor of the Sediment Trap should be concrete or grouted boulder lined to define sediment removal limits.

Flood Storage

Combining the water quality facility with a flood control facility is recommended. The 10-year and 100-year floods may be detained above the *ROCV*.

Multiple Uses

When desirable and feasible, incorporate the EDB within a larger flood control basin. Also, whenever possible, try to provide for other urban uses such as active or passive recreation, and wildlife habitat. If multiple uses are being contemplated, use the multiple-stage detention basin design approach to limit inundation of passive recreational areas to one or two occurrences a year.

The area within the *ROCV* is not suited for active recreation activities such as ballparks, playing fields, and picnic areas. These are best located above the *ROCV* level.

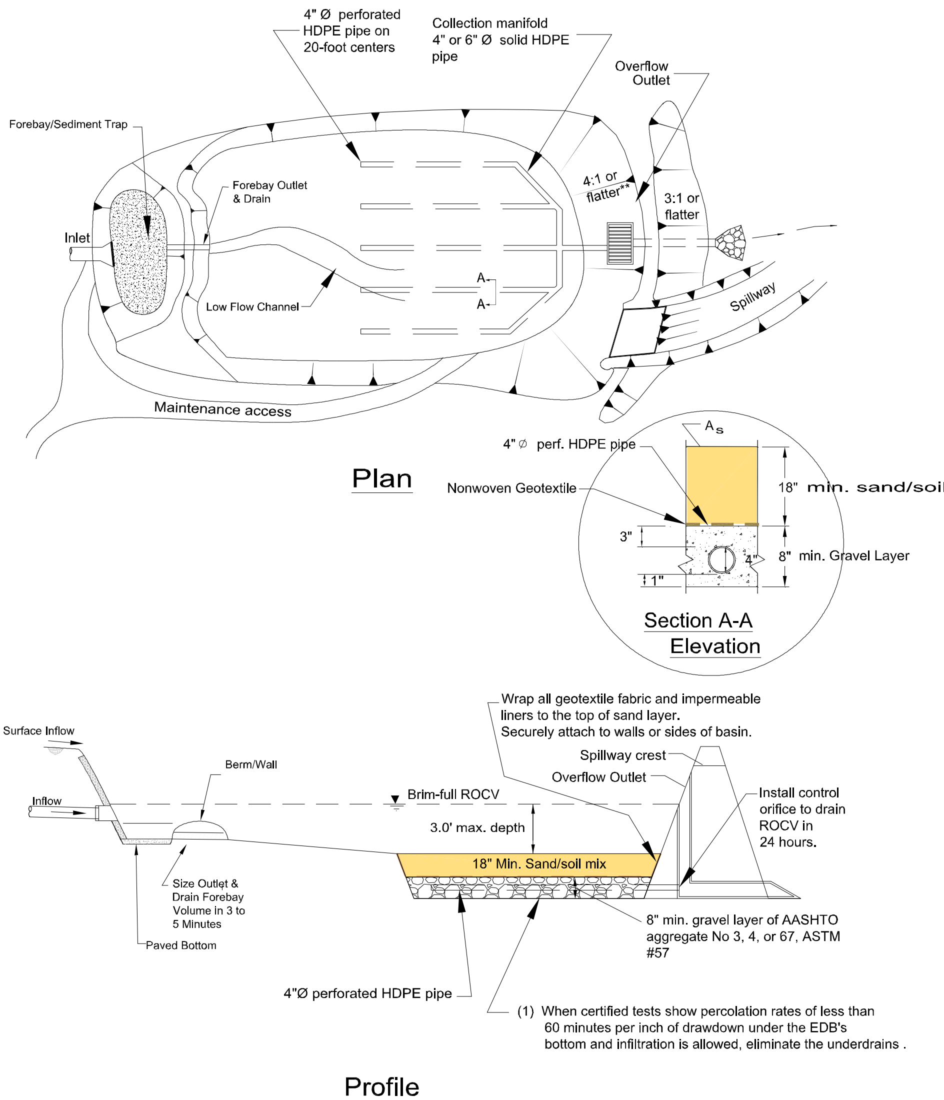


Figure 3.13 Extended Detention Basin

3.9. REFERENCES

[1] U.S. DOT, *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring – Dry and Wet Vegetated Swales*, Federal Highway Administration. http://www.fhwa.dot.gov/environment/ultraurb/3fs10.htm

4. OTHER BEST MANAGEMENT PRACTICE FACTSHEETS

Contents

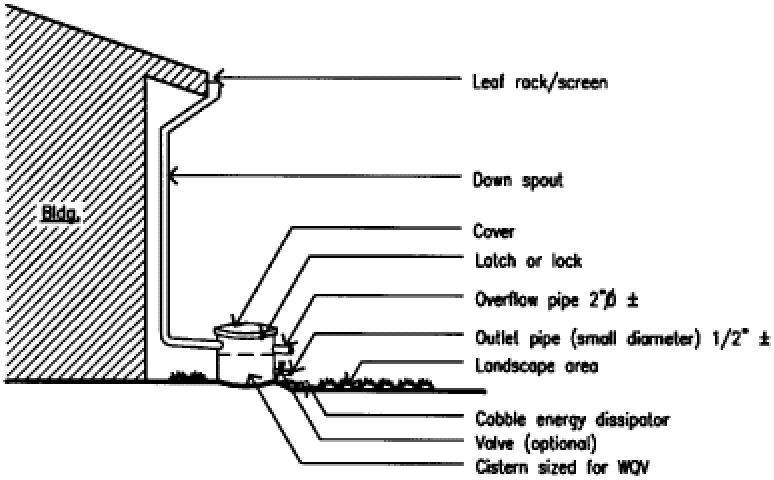
4.1. INTRODUCTION

LID site design uses planning and design strategies to minimize the quantity and improve the quality of stormwater from new development and redevelopment. The following fact sheets suggest techniques to reduce impervious surfaces, directly disconnect impervious areas from storm drains, maximize on-lot infiltration through vegetated and landscaped features, maximize multi-use open space, and minimize disturbance.

These fact sheets are intended to compliment the Engineered IMPs in the previous chapter. Any particular design detail can make a small difference in the overall impact of a development, but when implemented with other IMPs, these details can exert a profound influence on the ability of a development to meet stormwater management goals. These factsheets will should encourage planners, developers, engineers, and builders to utilize these opportunities to manage small quantities of runoff at many diverse locations throughout a site.

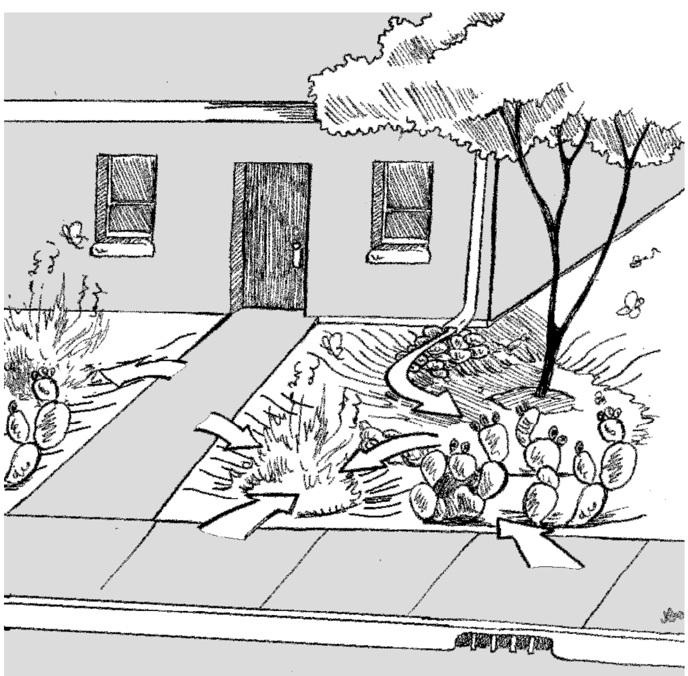
The techniques presented here are not all-inclusive, and may not be appropriate for every site or condition. The intent of these fact sheets is to encourage the use of, and foster the development of, alternative strategies where appropriate to reach water quality goals. This section was adapted from the County of San Diego Low Impact Development Handbook.

4.2. WATER HARVESTING



4.2.1. Description

A key LID technique is Rain Water Harvesting (RWH), the practice of collecting and reusing runoff from impervious surfaces. This can be as simple as directing the runoff to landscaped areas on site for irrigation and infiltration, or collecting and storing the runoff using rain barrels or cisterns (at smaller residential scales), and using above or below ground storage (at larger scales in commercial and light industrial developments). Rain Water Harvesting has been successful in reducing runoff discharged to the storm drain system and conserving water in applications at all scales. This is also an effective LID method in settings with soils relatively restrictive to infiltration.



Example of harvesting rainwater by directing runoff to landscaped areas.
(Graphic courtesy of Brad Lancaster and www.rainwaterharvesting.com)

From a hydrologic standpoint, collection and use of rooftop runoff reduces or removes the roof contribution from the surface water system. Collecting the appropriate percentage of total precipitation can simulate the amount of water that is naturally transpired and evaporated in a forested environment. As a result, the surface water system in the low impact development responds more like a forested system.

4.2.2. Characteristics

- Can be incorporated into the aesthetics of the building and garden.
- Reduces peak runoff and allows sediment to settle.
- Provides more infiltration benefits than connecting directly to storm drain.

4.2.3. Application

Rain water harvesting is used throughout the world in new and existing construction where the availability of water supplies is limited. The collected water can be used for drinking water (with treatment), in a greywater system for toilet flushing, and for irrigation and landscaping. Due to the complexity of RWH systems that provide water for indoor use, and the need for treatment and separate plumbing systems, only final use for irrigation and landscaping will be considered in this Manual.

Use of RWH will reduce or eliminate the runoff contribution from rooftops, which will be significant in medium to high density residential developments since rooftops are a large percentage of the total impervious area. Rain water harvesting has been used for a long time in the arid southwest and system components are readily available.

4.2.4. Design Considerations for Residential applications

- Manually operated valves can be closed to store stormwater for irrigation use or infiltration between storms.
- 1000 sf of roof will generate approximately 600 gallons of water from 1 inch of rainfall.
- Storage containers must be covered to prevent mosquitoes from breeding.
- Permanently open outlet must be sized appropriately.
- Size cistern for runoff control volume, provide overflow for larger storms.
- For safety reasons provide secure cover or ≤ 4” top opening if holding more than 6” depth of water.
- Provide screen on gutter and intake of outlet pipe to minimize clogging by leaves and other debris.
- Smaller aboveground residential rain barrels will likely freeze in the winter months and should have the outlet open during this time. Larger storage containers (greater than 500 gallons) are less likely to freeze but should be partially buried (or build a berm around the base) and kept substantially full to ensure it does not freeze.

4.2.5. Maintenance

- Small scale residential systems that direct runoff through landscape elements require little maintenance other than typical landscaping maintenance.
- Large scale systems require regular monitoring and cleaning.
- Ensure gutters and other conveyances are not clogged by leaves or other debris.

4.2.6. Advantages/Disadvantages

Rain water harvesting technologies are relatively simple and have a long-term impact on water resources by substituting captured water instead of potable or reuse water for landscaping. It also reduces the impact to downstream receiving channels by reducing the volume of water draining to them. Demand for potable water can be further reduced by using captured rainwater for non-potable household use, although all applicable building codes will have to be followed.

The uncertainty of rainfall make relying on RWH as the sole source of landscape water a difficult task, and may require a larger storage system to bridge the gaps between rainfall events. Although Flagstaff has a cold winter climate, above ground storage systems are generally not susceptible to freezing, especially if they are partially buried or insulated with earth or landscape material around the bottom of the tanks. Smaller residential rain barrels will freeze and therefore should have the outlet open during this time.

4.2.7. Economics

- Low installation costs

4.2.8. Additional Resources

For additional information pertaining to Rain Water Harvesting see the following:

Reuse/ Recycling/ Rainwater Harvesting, American Water Works Association. http://www.awwa.org/awwa/community/links.cfm?FuseAction=Links&LinkCategoryID=5

Rainwater Harvesting for Drylands and Beyond, Volume 1: Guiding Principles to Welcome Rain Into Your Life and Landscape, by Brad Lancaster, 2006
www.harvestingrainwater.com/books/volume1

Water Storage: Tanks, Cisterns, Aquifers and Ponds for Domestic Supply, Fire and Emergency Use, Plus How to Make Ferrocement Water Tanks, by Art Ludwig. Oasis Design, 2005
www.oasisdesign.net,

American Rainwater Catchment Systems Association
www.arcsa.org

Stormwater as a Resource: How to Harvest and Protect a Dryland Treasure, City of Santa Fe and the College of Santa Fe,
www.nmenv.state.nm.us/swqb/Storm_Water_as_a_Resource.pdf

Rainwater Harvesting, Texas AgriLife Extension Service. Texas A&M University
http://rainwaterharvesting.tamu.edu/rainwaterbasics.htm

The Texas Manual on Rainwater Harvesting, Third Edition, 2005: Texas Water Development Board
www.twdb.state.tx.us/iwt/rainwater/docs.html

Water Harvesting Guidance Manual: City of Tucson
http://dot.ci.tucson.az.us/stormwater/downloads/2006WaterHarvesting.pdf

Harvesting Rainwater for Landscape Use, 2nd ed., by Patricia H. Waterfall and Christina Bickelmann. Cooperative Extension, College of Agriculture and Life Sciences, University of Arizona.
www.cals.arizona.edu/pubs/water/az1344.pdf

Virginia Rainwater Harvesting Manual: Cabell Brand Center
www.cabellbrandcenter.org/CB%20Center%20webpage%20Current%20Projects.html

4.3. LID STREET DESIGN

Streets and roads account for a significant portion of the impervious coverage in a given area and are one of the largest contributors to stormwater and pollutant runoff. LID techniques strive to reduce this impact by reducing impervious coverage and maximizing storm water infiltration and pollutant uptake.

4.3.1. Characteristics

- Employs alternatives that reduce impervious coverage, such as reducing the length of the road network by exploring alternative street layouts.

4.3.2. Application

- Multiple techniques with a variety of applications can be utilized to achieve the goal of reducing impervious coverage and reducing pollutant runoff.
- Both city and rural streets have the potential for application of multiple LID techniques.
- Some possible applications include changes to road layout, street width, cul-de-sac design, use of permeable materials, utilization of traffic calming features as sites for LID components, curb-cuts, street-side swales, concave medians, as well as a number of others.

4.3.3. Design

- Reduce the length of residential streets by reviewing minimum lot widths and exploring alternative street layouts
- Clustering homes and narrowing lot frontages can reduce road length by reducing the overall development area.
- Another approach is to lengthen street blocks and reduce cross streets, providing pedestrian and bicycle paths mid-block to increase access.
- When siting streets, consider natural drainage patterns and soil permeability.
- Consider access for large vehicles, equipment, and emergency vehicles when designing alternative street layouts, and widths.
- Consider emergency access requirements and curve and sight distance requirements

4.3.4. Maintenance

- Narrower streets should cost less to maintain than wider streets as they present less surface area to maintain and repair.
- Landscaped and bioretention and traffic calming areas will require routine maintenance associated with these areas.

4.3.5. Limitations

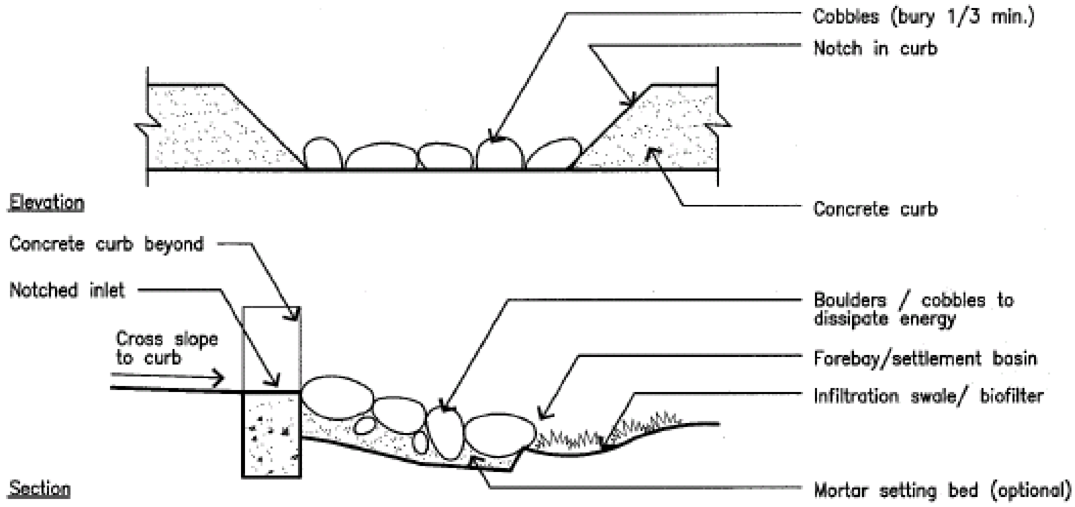
- Local zoning standards may require wide streets, sidewalks on one or both sides of streets, and curbed roads.
- Local zoning standards will also determine what other techniques may or may not be applicable.

- Arterial, collector and other street types with greater traffic volumes are not candidates for narrower streets.
- Street width and turnaround design need to accommodate emergency vehicles.

4.3.6. Economics

- Costs will vary based upon the techniques applied at each given location.
- Costs are also dependant on whether the application is a retro-fit or new construction.

4.4. CURB-CUTS



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

On streets where a more urban character is desired or where a rigid pavement edge is required, curb and gutter systems can be designed to empty into drainage swales. These swales can run parallel to the street, in the parkway between the curb and the sidewalk, or can intersect the street at cross angles, and run between residences, depending on topography. Runoff travels along the gutter, but instead of being emptied into a catch basin and underground pipe, multiple openings in the curb direct runoff into surface swales or infiltration/detention basins. If lined with ground cover or gravel/rock and gently sloped, these swales function as biofilters. Because concentration of flow will be highest at the curb opening, erosion control must be provided, which may include a settlement basin for ease of debris removal.

<u>Urban curb/swale</u> systems are a hybrid of standard urban curb and gutter with a more rural or suburban swale drainage system. It provides a rigid pavement edge for vehicle control, street sweeping, and pavement protection, while still allowing surface flow in landscaped areas for stormwater quality protection.

4.4.1. Characteristics

- Runoff travels along the gutter, but instead of being emptied directly into catch basins and underground pipes, it flows into surface swales.
- Stormwater can be directed into swales either through conventional catch basins with outfall to the swale or notches in the curb with flow line leading to the swale.
- Swales remove dissolved pollutants, suspended solids (including heavy metals, nutrients), oil and grease by infiltration.

4.4.2. Application

- Can be created in existing and new residential developments, commercial office parks, arterial streets, concave median islands.
- Swale system can run either parallel to roadway or perpendicular to it, depending on topography and adjacent land uses.

4.4.3. Design

- Size curb-openings or catch basins for design storm.
- Multiple curb openings closely spaced are better than fewer openings widely spaced because it allows for greater dissipation of flow and pollutants.
- Provide energy dissipaters at curb notches or catch basin outfall into swale.
- Provide settlement basin at bottom of energy dissipater to allow for sedimentation before water enters swale.
- Curb cuts should be at least 12 inches wide to prevent clogging.
- Curb cuts should have a vertical drop in addition to sufficient width to prevent clogging.
- Ensure access is provided to perform maintenance.

4.4.4. Maintenance

- Annual removal of built-up sediment in settlement basin may be required.
- Catch basins require periodic cleaning.
- Inspect system prior to rainy season and during or after large storms.

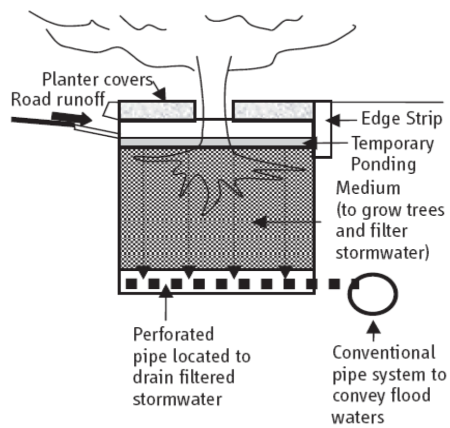
4.4.5. Limitations

- Parking requirements and codes

4.4.6. Economics

- Cobble-lined curb opening may add marginal cost compared to standard catch basin.
- Swale system requires periodic landscape maintenance.

4.5. STREET TREES



Tree planter schematic

Trees can be used as a stormwater management tool in addition to providing the more commonly recognized benefits of energy conservation, air quality improvement, and aesthetic enhancement.

4.5.1. Characteristics

- Tree surfaces (roots, foliage, bark, and branches) intercept, evaporate, store or convey precipitation to the soil before it reaches surrounding impervious surfaces.
- In bioretention cells or swales, tree roots build soil structure that enhances infiltration capacity and reduces erosion.

4.5.2. Application

- Using modified planter boxes as opposed to the tradition approach can provide stormwater filtration in an otherwise impervious urban environment.
- Modified street tree planters are appropriate for use along streets, sidewalks, driveways and other urban settings.
- Medians and traffic calming bays can also be utilized as bioretention systems using systems such as street trees.

4.5.3. Design

- Appropriate placement and selection of tree species is important to achieve desired benefits and reduce potential problems such as pavement damage by surface roots and poor growth performance.
- Check with planning guidelines for the type and location of trees planted along public streets or rights-of-way.
- The extent and growth pattern of the root structure must be considered when trees are planted in bioretention areas or other stormwater facilities with under-drain

structures or near paved areas such as driveways, sidewalks or streets. Root barrier devices can be utilized where applicable.

- Available growing space must also be considered in site planning.
- Soil type and water availability must be considered in species choice and placement.
- Underground utilities and overhead wires must be circumvented.
- Additional functions desired, such as shade, aesthetics, windbreak, privacy screening, should impact species choice and placement as well
- Other important tree characteristics to consider when making a selection include: Longevity or life-span, Tolerance for urban pollutants, Growth Rate, Tolerance to drought, seasonally saturated soils, and poor soils, Canopy spread and density, Foliage texture and persistence.
- Provide cleanouts for maintenance of the underdrain system.

4.5.4. Maintenance

- In general, maintenance includes annual routine inspection and maintenance activities.
- These would include removal of trash, debris and sediment, replenishment of the mulch, and care or replacement of plants.
- During extreme droughts the plants may need to be watered in the same manner as any other landscape material.

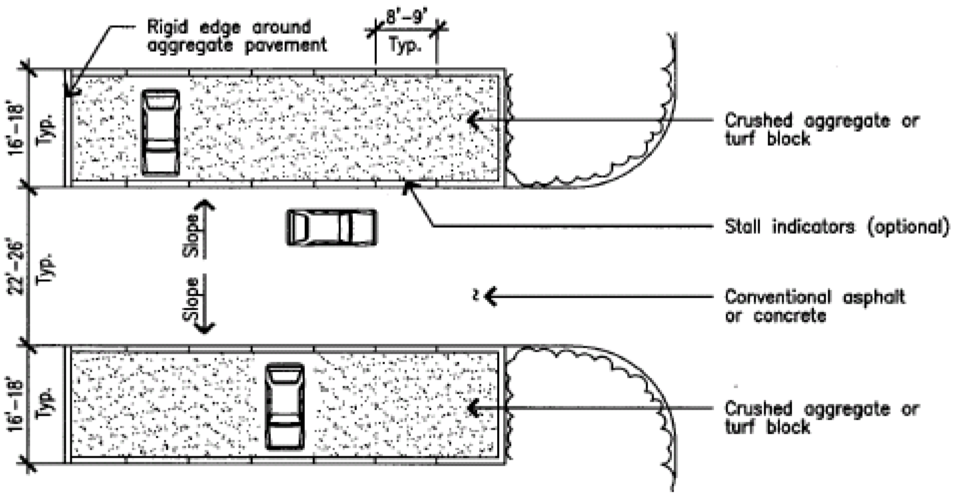
4.5.5. Limitations

- Local planning guidelines and zoning provisions for the permissible species and placement of trees along public streets or rights-of-way must be consulted.
- Vehicle and pedestrian sight lines; proximity to paved areas and underground utilities; proximity to neighbors, buildings, and other vegetation; prevailing wind direction; and sun exposure all must be considered in street tree placement.
- Species appropriate is dependant upon the available space for root and foliage growth, location of utilities such as water pipes and power lines, available water (irrigation should be limited as much as possible) and tolerance to pollutants.

4.5.6. Economics

- Accurate economic data pertaining to the use of subsurface reservoir beds is currently unavailable, however, site specific cost records can be found in the LID Literature Index.

4.6. HYBRID PARKING LOT



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Hybrid parking lots differentiate paving, combining impervious aisles with permeable stalls. Impervious aisles are designed to carry moving vehicle traffic and accommodate turning movements. Permeable stalls are designed for stationary or very slow moving cars. There are many possible combinations of materials.

4.6.1. Characteristics

- Hybrid lots can reduce the overall impervious surface coverage of a typical double-loaded parking lot by 60%, and reduce the need for an underground drainage system.
- Differentiation between aisles and stalls can mitigate the overall visual impact of the parking lot.

4.6.2. Application

- Commercial areas, offices, multi-family housing, hotels, restaurants.
- Selection of permeable pavement material depends on use. Permeable asphalt, pervious concrete or unit pavers are recommended for stalls in areas with high turnover, such as restaurants. Areas with low turnover, such as hotels, office buildings, and housing can use crushed aggregate for stalls.
- Variable permeability, depending on pavements chosen.
- High ground water or lack of deep, permeable soils may limit applications.

4.6.3. Design

- Keep permeable pavement areas relatively flat (slope ≤ 5%)
- Aisles are constructed of conventional asphalt or concrete suitable for heavier traffic use, speeds between 10 and 20 mph, and designed to support the concentrated traffic of all vehicles using the lot.

- Stalls are constructed of a permeable pavement, such as open-graded crushed aggregate, open-celled unit pavers, turf block, permeable asphalt, or pervious concrete.
- Avoid using permeable pavement in areas with underground utilities. If it is necessary to use permeable pavement in these areas, care must be taken to keep infiltrated water form migrating into utility trench bedding.
- Slope aisles into adjacent permeable stalls.
- Subdrain or overflow drainage may be required depending on design storm and underlying soils.
- Stall markings can be indicated with wood headers laid in field of permeable pavement, change in unit paver color, concrete bands or pavement markers ("Botts dots"), depending on the material used.
- Designated handicapped stalls must be made of an ADA compliant pavement.

4.6.4. Maintenance

- Periodic weed control, sweeping, and regrading required for gravel stalls.
- Irrigation, fertilizer, weed control, and mowing required for turf block stalls. Pressure hosing or vacuum sweeping may be required for pervious concrete or permeable asphalt stalls.

4.6.5. Limitations

- Limitations are related to the materials used (for example, if stalls are constructed of crushed aggregate, the limitations associated with crushed aggregate would apply to the hybrid parking lot).
- Space limitations and soil type might affect the types of pavements that can be used.

4.6.6. Economics

- Reduction of overall impervious surface coverage may eliminate or reduce need for underground drainage system.
- Construction cost will depend on materials chosen. A hybrid lot of conventional asphalt aisles with crushed aggregate stalls will be lower cost than a lot entirely paved in asphalt. A hybrid lot of conventional asphalt aisles with unit pavers stalls will be higher cost than a lot entirely paved in asphalt.

4.6.7. Downspout to Swale

Discharging a roof downspout to landscaped areas via swales allows for polishing and infiltration of the runoff.

4.6.8. Characteristics

- Runoff from the roof is directed into a rocky or vegetated swale area.
- The water flows through swale with overflow continuing to the storm drain.

4.6.9. Application

- Appropriate for most buildings with landscaped areas adjacent to the building where soil drainage is appropriate and water infiltration does not pose a risk to the foundation.

4.6.10. Design

- The downspout can be directly connected to a pipe which daylights some distance from the building foundation, releasing the roof runoff into a rock lined swale towards a landscaped area.
- The roof runoff is slowed by the rocks, absorbed by the soils and vegetation, and remaining runoff flows away from the building foundation into the storm drain.
- Xeriscape techniques, natural stone and rock linings should be used as an alternative to turf.

4.6.11. Maintenance

- Maintenance is similar to that necessary for other swale areas and will depend on the specific style chosen.

4.6.12. Limitations

- Only suitable for grades between 1% and 6%
- When a vegetated swale is used, the site requires adequate sunlight for vegetation growth
- Avoid infiltrating too close to foundations and underground utilities.

4.6.13. Economics

- Costs are similar to those associated with other swale devices.

4.7. VEGETATED ROOFS

Vegetated roofs serve to treat stormwater pollutants, reduce runoff volumes, provide additional landscape amenity, provide acoustical control, air filtration and create urban wildlife habitat. Vegetated roofs also provide oxygen production, carbon storage, increase insulation and extend the expected lifetime of the roof compared to conventional roofing.

Green roof at University of Northern Arizona's Applied Research and Development facility.

4.7.1. Characteristics

- Roofs can be either extensive or intensive or vegetation can be placed in modules.
- Extensive: Consists of shallow (1"-6"), lightweight substrate and a few types of low-profile, low-maintenance, drought-tolerant plants
- Intensive: Consists of thicker (8"-48") substrate can support a richer variety of plant material and a more garden-like appearance
- Vegetated walls are facades of steel cables that hold climbing plants away from the surface of the building.

4.7.2. Application

- Can be installed on almost any building with slopes up to 40 degrees
- Vegetated roofs are effective strategies for managing stormwater in highly urbanized settings where rooftops comprise a large percentage of the total impervious surface.
- Can be an effective way of reducing energy costs in a conservation-conscious way

4.7.3. Design

- Construction should be performed by an experienced vegetated roof specialist.
- Extensive roofs utilize light-weight soil mixes to reduce loads. Native soils are usually too heavy when wet for roof usage.
- Structural capacity of the roof must be designed to support up the anticipated additional loads.
- A living non-irrigated vegetated roof in Flagstaff is possible to maintain and will perform a stormwater benefit; however irrigation may be required during Xeriscape plant establishment. Consult an experienced vegetated roof specialist.
- Extensive green roof systems contain several layers of protective materials to convey water away from the roof deck. These generally include (from the bottom up) a waterproof membrane, a root barrier, a layer of insulation, a drainage layer, a filter fabric for fine soils, the engineered growing medium or soil substrate, and the plant material.
- Sedums, a common vegetated roof plant, have fleshy water-storing leaves that do not burn easily, even in near drought conditions.

4.7.4. Maintenance

- Installations require regular inspection and maintenance to guarantee proper functioning of any drainage or irrigation components as well as for removal of dead or diseased vegetation
- As needed, pruning and weeding must occur in order to maintain the appearance of the roof. Weeding and removal of dead material should be scheduled to coincide with important horticulture cycles.
- Intensive vegetated roofing may require more frequent inspection and maintenance.
- Intensive installations may also require irrigation as needed. Extensive installations should not be irrigated unless deemed absolutely necessary.
- Soils may also need to be tested for pH periodically and neutralizing agents may need to be employed as needed.

4.7.5. Limitations

- Installing a vegetated roof with a pitch of greater than 20 percent increases project complexity and requires supplemental anchoring.
- A slight pitch is preferable for efficient drainage but may not be as necessary in the arid environment.
- Sun exposure must be considered as both pitch and neighboring buildings may limit the amount of sunlight the vegetation receives, which can inhibit growth and the other beneficial effects of a vegetated roof.
- The site must have sufficient structural strength the hold the load of the vegetated roof at its most water saturated.
- Fire safety provisions must be abided by and may affect the location and the extent of vegetated roofing that is allowed.

4.7.6. Economics

- Costs vary based upon system implemented.
- Vegetated roof savings have been reported to offset annual energy costs.

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5. MAINTENANCE RECOMMENDATIONS

Contents

5.1. INTRODUCTION

Once they are constructed, IMPs are crucial in protecting water quality from the impacts of development projects. If designed correctly, BMPs can also be an aesthetic asset to the development. However, no matter how well they are designed and constructed, IMPs will not function correctly nor look attractive unless they are properly maintained. Most maintenance problems with IMPs are less costly to correct when they are caught early.

This section presents general maintenance guidance consisting of a table explaining the minimum inspection and maintenance activities required to ensure the proper functioning of the IMP detailed in the Engineered IMP section of this Manual. It is expected that these maintenance recommendations will become more robust as experience is gained over time. Additionally, an Operation and Maintenance Plan is required to be submitted with all LID designs.

5.2. VEGETATED BUFFER STRIP (VB)

Vegetated buffers require general maintenance of the native vegetation cover and repair of any rill or gully development. Table 5.1 presents a summary of specific maintenance requirements and a suggested frequency of action.

Table 5.1 Vegetated Buffer Strip Maintenance Considerations

3. Required Action	Maintenance Objective	Frequency of Action
Lawn mowing	Maintain a dense native vegetation cover at a recommended length of 2 to 4 inches. Collect and dispose of cuttings offsite or use a mulching mower.	Routine – As needed or recommended by inspection.
Lawn care	Use the minimum amount of biodegradable, nontoxic fertilizers and herbicides needed to maintain dense native vegetation cover, free of weeds. Reseed and patch damaged areas.	Routine – As needed.
Litter removal	Remove litter and debris to prevent gully development, enhance aesthetics, and prevent floatables from being washed offsite.	Routine – As needed by inspection.
Inspections	Inspect irrigation, native vegetation density, flow distribution, gully development, and traces of pedestrian or vehicular traffic and request repairs as needed.	Annually and after each major storm (that is, larger than 0.75 inches in precipitation).
Turf replacement	To lower the turf below the surface of the adjacent pavement, use a level flow spreader, so that sheet flow is not blocked and will not cause water to back up onto the upstream pavement.	As needed when water ponding becomes too high or too frequent a problem. The need for turf replacement will be higher if the pavement is sanded in winter to improve tire traction on ice. Otherwise, expect replacement once every 5 to 15 years.

5.3. VEGETATED/ROCK SWALES (VRS)

Table 5.2 summarizes maintenance needs and related issues and shows the recommended frequency of various maintenance activities.

Healthy native vegetation can generally be maintained without using fertilizers because runoff from lawns and other areas contains the needed nutrients. Occasionally inspecting the native vegetation and/or rock over the first few years will help to determine if any problems are developing and to plan for long-term restorative maintenance needs.

Table 5.2 Vegetation-Lined Swale Maintenance Considerations

Required Action	Maintenance Objective	Frequency of Action
Lawn mowing and Lawn care	Maintain grass at 2 to 4 inches tall and nonirrigated native grass at 6 to 8 inches tall. Collect cuttings and dispose of them offsite or use a mulching mower.	Routine – As needed.
Debris and Litter removal	Keep the area clean for aesthetic reasons, which also reduces floatables being flushed downstream.	Routine – As needed by inspection, but no less than two times per year.
Sediment removal	Remove accumulated sediment near culverts and in channels to maintain flow capacity. Replace the grass areas damaged in the process.	Routine – As needed by inspection. Estimate the need to remove sediment from 3 to 10 percent of total length per year, as determined by annual inspection.
Grass reseeding and mulching	Maintain a healthy dense grass in channel and side slope.	Nonroutine – As needed by annual inspection.
Inspections	Check the grass for uniformity of cover, sediment accumulation in the swale, and near culverts.	Routine – Annual inspection is suggested.

5.4. POROUS PAVEMENT (PP)

5.4.1. Modular Block Pavement (MBP)

Table 5.3 Modular Block Porous Pavement Maintenance Considerations

Required Action	Maintenance Objective and Action	Frequency of Action
Debris and litter removal	Accumulated material should be removed as a source control measure.	Routine – As needed.
Sod maintenance	If sandy loam turf is used, provide lawn care, irrigation system, and inlay depth maintenance as needed.	Routine – As dictated by inspection.
Inspection	Inspect representative areas of surface filter sand or sandy loam turf for accumulation of sediment or poor infiltration.	Routine and during a storm event to ensure that water is not bypassing these surfaces on frequent basis by not infiltrating into the pavement.
Rehabilitating sand infill surface	To remove fine sediment from the top of the sand and restore it's infiltrating capacity.	Routine – Sweep the surface annually and, if need be, replace lost sand infill to bring its surface to be ¼ below the adjacent blocks.
Replacement of Surface Filter Layer	Remove, dispose, and replace surface filter media by pulling out turf plugs or vacuuming out sand media from the blocks. Replace with fresh ASTM C-33 sand or sandy loam turf plugs, as appropriate.	Nonroutine – When it becomes evident that runoff does not rapidly infiltrate into the surface. May be as often as every two year or as little as every 5 to 10 years.
Replace modular block pavement	Restore the pavement surface. Remove and replace the modular pavement blocks, the sand leveling course under the blocks and the infill media when the pavement Surface shows significant deterioration.	Nonroutine – When it becomes evident that the modular blocks have deteriorated significantly. Expect replacement every 10 to 15 years dependent on use and traffic.

5.4.2. Permeable Interlocking Concrete Pavers (PICP)

Table 5.4 Permeable Interlocking Concrete Paver Maintenance Considerations

Required Action	Maintenance Objective and Action	Frequency of Action
Debris and litter removal	Accumulated material should be removed as a source control measure.	Routine – As needed.
Inspection	Inspect representative areas of surface filter fine gravel infill for accumulation of sediment and poor infiltration.	Routine and during a storm events to ensure that stormwater is infiltrating and not bypassing the pavement surface on frequent basis.
Rehabilitating fine grave infill surface	To remove fine sediment and trash accumulations from the top of the gravel and restore its infiltrating capacity.	Routine – Vacuum sweep as indicated by inspection and if need be replace lost or clogged gravel infill to bring its surface to be ¼ below the adjacent blocks.
Replace cobble block pavement	Restore the pavement surface. Remove and replace the cobble pavement blocks, the leveling course under the blocks, the infill media, gravel base and geotextile materials when the pavement surface shows significant deterioration or when the pavement no longer infiltrates stormwater at rates that are acceptable.	Nonroutine – When it becomes evident that the modular blocks have deteriorated significantly and the underlying gravels have accumulated much sediment and/or when the geotextile fabrics underneath it are clogged. Expect replacement every 10 to 25 years dependent on use and traffic.

5.5. REINFORCED GRASS PAVEMENT (RGP)

Table 5.5 Reinforced Grass Pavement Maintenance Considerations

Required Action	Maintenance Objective and Action	Frequency of Action
Debris and litter removal	Accumulated material should be removed as a source control measure.	Routine – As needed.
Inspection	Inspect all surface areas for healthy grass growth, areas of dead grass, tire rutting, surface erosion, accumulation of sediment and slow infiltration.	Routine and during a storm events to ensure that water is infiltrating and not bypassing the pavement's surface on frequent basis.
Repair sod surface	To repair worn out or damaged sod with sod grown in very sandy loam type soils.	Routine – As needed. Repairs may be needed as often as every year.
Repair and replacement of sod	Major repair of damaged and aged sod. Remove and replace, as needed the sod layer to maintain a healthy vegetative cover or when sod layer builds up significant amount of silt (i.e., >1.5 inches) above the originally installed surface layer.	Nonroutine – When it becomes evident that many parts of the sod has deteriorated or when runoff does not rapidly infiltrate into the surface. Major replacement of sod may be as little as every 10 to 25 years.

5.6. POURED POROUS CONCRETE PAVEMENT (PCP)

Table 5.6 Poured Porous Concrete Pavement Maintenance Considerations

Required Action	Maintenance Objective and Action	Frequency of Action
Debris and litter removal	Accumulated material should be removed as a source control measure.	Routine – As needed.
Inspection	Inspect all areas of pavement for accumulation of sediment, pavement deterioration, unraveling and poor infiltration.	Routine and during a storm events to ensure that water is infiltrating and not bypassing the pavement surface on frequent basis. Unraveling pavement may need structural repairs or patching.
Vacuuming and high pressure wash of pavement	Vacuum using high-energy street vacuuming equipment to remove accumulating sediment from pavement pores then follow-up with high-pressure wash to scour out the accumulated fines in the pores of the pavement.	Routine – Every year, but may be extended to every two to three years if routine inspections show the infiltration rates continue to be high. Very important to maintain surface infiltration and good flow through of water through the full section of the concrete slab to extend it life during freeze-thaw cycles in colder climates.
Replacement of Concrete Pavement, Geotextile Fabric, and Base Course	Remove, dispose, and replace porous concrete slab when it shows excessive deterioration and when it no longer infiltrates stormwater quickly. Inspect the full section of the pavement when the concrete layer is removed for accumulation of sediments in the Base Course. Remove and dispose accumulated sediments and replace Base Course, and geotextile fabrics.	Nonroutine – When it becomes evident that runoff does not rapidly infiltrate into the surface or into the underdrains underneath or into the soils if underdrains are not present. May be as often as every 10 to year or as little as every 20 to 30 years.

5.7. REINFORCED POROUS GRAVEL PAVEMENT (RPGP)

Table 5.7 Porous Gravel Pavement Maintenance Considerations

Required Action	Maintenance Objective and Action	Frequency of Action
Debris and litter removal	Accumulated material should be removed as a source control measure.	Routine – As needed.
Inspection	Inspect all areas of surface for accumulation of sediment and debris, slow infiltration, and exposed support grid.	Routine and during storm events to ensure that water is infiltrating and not bypassing the pavement surface on frequent basis. Rake or broom gravel over exposed grid.
Snowplowing	RPGP areas can be easily plowed of snow using standard truck-mounted snowplow blades with small skids on the corners of the blades to keep the bottom of the blade off the surface approximately 1". This eliminates product damage and reduces gravel migration. The surface should be at or slightly below, that of adjacent hard surfaces to avoid gouging. Avoid long-term pileup of snow on RPGP surfaces to avoid concentrated sedimentation accumulation.	As needed.
Replace contaminated surface gravels	When inspection shows accumulations of sediment and debris on top of gravel or top layers of gravel appear to be sealing and slow infiltration is occulting remove the top few inches of gravel and replace with clean ASSHTO #4 gravel.	Mostly Routine – May need this action as often as every year of as infrequently as every 5 years.

5.8. POROUS PAVEMENT DETENTION (PDP)

Table 5.8 Porous Pavement Detention Maintenance Considerations

4. Required Action	Maintenance Objective	Frequency of Action
Debris and litter removal	Accumulated material should be removed as a source control measure.	Nonroutine – As needed.
Inspection	Inspect representative areas of surface sand/soil accumulation of fine sediment.	Routine and during a storm event to ensure that water is not bypassing these surfaces or taking too long to drain out.
Replacement of surface filter layer	Using a power vacuum remove all sand media within the annular spaces of the concrete blocks. Replace with fresh ASTM C-33 sand, vibrate into place and remove excess.	Nonroutine – When it becomes evident that runoff does not rapidly infiltrate into the surface, namely, the ponded water does not drain within one hour. May be as often as once a year or as little as once every 5 to 10 years.

5.9. BIO-RETENTION (BR)

Table 5.9 Bio-Retention Maintenance Considerations

5. Required Action	Maintenance Objectives	Frequency
Lawn mowing and vegetative care	Occasional mowing of grasses and weed removal to limit unwanted vegetation. Maintain irrigated turf grass as 2 to 4 inches tall and nonirrigated native turf grasses at 4 to 6 inches.	Routine – Depending on aesthetic requirements.
Inspections	Inspect detention area to determine if the sandy growth media is allowing acceptable infiltration.	Routine – Annual inspection of hydraulic performance.
Debris and litter removal	Remove debris and litter from detention area to minimize clogging of the sand media.	Routine – Depending on aesthetic requirements.
Landscaping removal and replacement	The sandy loam turf and landscaping layer will clog with time as materials accumulate on it. This layer will need to be removed and replaced to rehabilitate infiltration rates, along with all turf and other vegetation growing on the surface,.	Every 5 to 15 years, depending on infiltration rates needed to drain the ROCV in 24-hours or less. May need to do it more frequently if exfiltration rates are too low to achieve this goal.

5.10. EXTENDED DETENTION BASINS (EDB)

Extended detention basins have low to moderate maintenance requirements. Routine and nonroutine maintenance is necessary to assure performance, enhance aesthetics, and protect structural integrity. The dry basins can result in nuisance complaints if not properly designed or maintained. Frequent debris removal and grass-mowing can reduce aesthetic complaints. If a shallow wetland or marshy area is created, mosquito breeding and nuisance odors could occur if the water becomes stagnant. Access to critical elements of the pond (inlet, outlet, spillway, and sediment collection areas) must be provided. The basic elements of the maintenance requirements are presented in Table 5.10.

Table 5.10 Extended Detention Basin Maintenance Considerations

Required Action	Maintenance Objective	Frequency of Action
Lawn mowing and lawn care	Occasional mowing to limit unwanted vegetation. Maintain native turf grasses at 4 to 6 inches.	Routine – Depending on aesthetic requirements.
Debris and litter removal	Remove debris and litter from the entire pond to minimize outlet clogging and improve aesthetics.	Routine – Including just before annual storm seasons (that is, April and May) and following significant rainfall events.
Sediment removal from forebay and micro-pool	Remove accumulated sediment from the forebay.	Routine – The sediment accumulations forebay will need to be cleaned out every one to three years.
Nuisance control	Address odor, insects, and overgrowth issues associated with stagnant or standing water in the bottom zone.	Nonroutine – Handle as necessary per inspection or local complaints.
Erosion and sediment control	Repair and revegetate eroded areas in the basin and channels.	Nonroutine – Periodic and repair as necessary based on inspection.
Structural	Repair pond inlets, outlets, forebays, low flow channel liners, and energy dissipators whenever damage is discovered.	Nonroutine – Repair as needed based on regular inspections.
Inspections	Inspect basins to insure that the basin continues to function as initially intended. Examine the outlet for clogging, erosion, slumping, excessive sedimentation levels, overgrowth, embankment and spillway integrity, and damage to any structural element.	Routine – Annual inspection of hydraulic and structural facilities. Also check for obvious problems during routine maintenance visits, especially for plugging of outlets.
Scarify filter surface	Scarify top 3 inches by raking the filter's surface.	Once per year or when needed to promote drainage.
Sediment removal	Remove accumulated sediment from the bottom of the basin.	Nonroutine – Performed when sediment accumulation occupies 20 percent of the ROCV. This may vary considerably, but expect to do this every 15 to 25 years, as necessary per inspection if no construction activities take place in the tributary watershed. More often if they do.

APPENDIX A GLOSSARY

Aquifer	The underground layer of rock or soil in which groundwater resides. Aquifers are replenished or recharged by surface water percolating through soil. Wells are drilled into aquifers to extract water for human use.
AASHTO	American Association of State Highway and Transportation Officials
Average Daily Traffic (ADT)	The average total number of vehicles that traverse a road or highway on a typical day. Often used to classify and design roadway systems.
IMP	Best Management Practice
Biofilter	Any of a number of devices used to control pollution using living materials to filter or chemically process pollutants.
Bioretention	A technique that uses parking lot islands, planting strips, or swales to collect and filter urban stormwater, that includes grass and sand filters, loamy soils, mulch, shallow ponding and native trees and shrubs.
Buffer	A zone created or sustained adjacent to a shoreline, wetland or stream where development is restricted or prohibited to minimize the negative effects of land development on animals and plants and their habitats.
Catchment	The smallest watershed management unit, defined as the area of a development site to its first intersection with a stream, usually as a pipe or open channel outfall.
Check dam	(a) A log or gabion structure placed perpendicular to a stream to enhance aquatic habitat. (b) An earthen or log structure, used in grass swales to reduce water velocities, promote sediment deposition, and enhance infiltration.
Cluster Development	A development pattern for residential, commercial, industrial, institutional, or combination of uses, in which the uses are grouped or "clustered," rather than spread evenly throughout the parcel as in conventional lot-by-lot development. A local jurisdiction may authorize such development by permitting smaller lot sizes if a specified portion of the land is kept in permanent open space to provide natural habitat or open space uses through public or private

dedication.

Contamination The impairment of water quality by waste to a degree that creates a hazard to public health through poisoning or through the spread of disease.

Cul-de-Sac A circular section located at the end of an access street that permits vehicles to turn around.

Curbs A concrete barrier on the margin of a road that separates vehicular and pedestrian traffic and is used to direct stormwater runoff to an inlet, protect pavement edges, and protect lawns and sidewalks from encroachment by vehicles.

Density The average number of families, persons, or housing units per unit of land. Usually density is expressed in "(number of) units per acre".

Design Storm A rainfall event of specified duration, intensity, and return frequency (e.g., a 2 year 6 hour event) that is used to calculate runoff volume and peak discharge rate.

Detention The temporary storage of storm runoff which is used to control discharge rates sufficiently to provide gravity settling of pollutants.

Detention Time The amount of time water actually is present in a basin. Theoretical detention time for a runoff event is determined from the period of release from the basin.

Disturbance The act of moving, grading, tilling, clearing, taking or repositioning the natural environment's soil surfaces and/or vegetation that was previously undisturbed by man.

Directly Connected Impervious Area (DCIA) The square footage of all impervious surfaces (see "Impervious Surface Area") that flow directly into a conveyance stormwater system.

Drainage Basin A land area bounded by high points, which drains all surface water into a single stream, other body of water, or storm drain infrastructure. (see Watershed)

Drought Tolerant Plant	The degree to which a plant is adapted to arid or drought conditions
Ephemeral Stream	A stream or waterway that holds water only for a few hours or days, then evaporates shortly after rain storms.
Erosion	The wearing away of land surface by wind or water. Erosion occurs naturally from weather or runoff but can be intensified by land-clearing practices related to farming, residential, commercial or industrial development, road building, or timber cutting.
Evapotranspiration	The combined loss of water from a given area, occurring during a specified period of time, by evaporation from the soil surface and transpiration from plants into the atmosphere.
Evaporation Practices	Practices that temporarily store runoff and provide for its evaporation. (e.g.: retention, detention, reservoirs, etc.).
Excess Parking	Parking spaces that are constructed over and above the number required or predicted based on the parking demand ratio for a particular land use or activity.
Filter Fabric	A textile of relatively small mesh or pore size that is used to either allow water to pass through while keeping sediment out (permeable), or prevent both runoff and sediment from passing through (impermeable).
Filter Strips	A vegetated area that treats sheetflow and/or interflow to remove sediment and other pollutants. Filter strips are used to treat shallow concentrated stormflows over very short contributing distances in urban areas.
First Flush	The delivery of a disproportionately large load of pollutants during the early part of storms due to the rapid runoff of accumulated pollutants. The first flush of runoff can be defined in several ways (e.g., one-half inch per impervious acre).
Forebay	An extra storage space provided near an inlet of a wet pond or constructed wetland to trap incoming sediments before they accumulate in the pond.

Gabion	A basket or cage filled with earth or rocks used for retaining walls, temporary floodwalls, to filter silt from runoff, and for small or temporary/permanent dams. They are also used to direct the force of a flow of flood water around a vulnerable structure and to protect slopes against erosion.
Green Space	The proportion of open space in a cluster development that is retained in an undisturbed vegetative condition.
Groundwater	Water stored underground that fills the spaces between soil particles or rock fractures. A zone underground with enough water to withdraw and use for drinking water or other purposes is called an aquifer.
Habitat	The specific area or environment in which a particular type of plant or animal lives. An organism's habitat must provide the basic requirements for life and should be free of harmful contaminants.
Hammerhead	A "T" shaped turnaround option for lightly traveled residential roads. This road type creates less impervious cover as compared to a circular cul-de-sac.
Heat Island Effect	The increase in ambient temperatures generated by heat radiating from paved surfaces exposed to sunlight.
Hybrid Parking Lots	A parking lot that uses multiple paving techniques to better utilize the area by combining impervious aisles with permeable stalls.
Hydrology	The science of the behavior of water in the atmosphere (air), on the surface of the earth, and underground.
Impermeable	Not able to be infiltrated by water.
Impervious Surface	Any surface which cannot be effectively (easily) penetrated by water. Examples include conventional pavements, buildings, highly compacted soils, and rock outcrops.
Impervious surface area	The ground area covered or sheltered by an impervious surface, measured in plan view (i.e., as if from directly above). For example, the "impervious surface area" for a pitched roof is equal to the

ground area it shelters, rather than the surface area of the roof itself.

Imperviousness The level of (or percentage of) impervious surface within a development site or watershed.

Infill Developing vacant parcels or redeveloping existing property within urban or sub-urban areas.

Infiltration The downward entry of water into the surface of the soil, as contrasted with percolation which is movement of water through soil layers.

Infiltration Basin A concave vegetated surface (e.g., pond) designed to hold water so that it can gradually infiltrate into the soil.

Modular Block Pavers (MBP) Concrete block units with open surface voids laid on a gravel subgrade. Use as a type of porous/permeable pavement.

Natural Drainage A drainage consisting of native soils such as a natural swale or topographic depression which gathers and/or conveys runoff to a permanent or intermittent watercourse or waterbody.

Nonpoint Source Pollution Pollution that enters water from dispersed and uncontrolled sources, such as rainfall or snowmelt, moving over and through the ground rather than a single, identifiable source. A nonpoint source is any source of water pollution that does not meet the legal definition of point source in section 502(14) of the Clean Water Act (e.g., agricultural practices, on site sewage disposal, automobiles, and recreational boats). While individual sources may seem insignificant, they may contribute pathogens, suspended solids, and toxicants which result in significant cumulative effects.

National Pollutant Discharge Elimination System (NPDES) A provision of the Clean Water Act that prohibits discharge of pollutants into waters of the United States unless a special permit is issued by EPA, a state, or another delegated agency.

Native or Low Water Use Plant A plant that occurs naturally in an area or has existed there for many years. The plant is adapted to living in the local conditions with its specific climate and soil conditions. Native plant communities are typically diverse in species makeup and structure. They also provide food and shelter for a variety of other

	organisms, living in community with them. Native plants use less water and are more adaptable than non-native plants.
Natural Resources Conservation Service (NRCS) Soil Classifications	The soils in the United States are placed into four groups, A, B, C, and D, and three dual classes, A/D, B/D, and C/D. In the definitions of the classes, infiltration rate is the rate at which water enters the soil at the surface and is controlled by the surface conditions. Transmission rate is the rate at which water moves in the soil and is controlled by soil properties. Definitions of the classes are as follows: A.(Low runoff potential). The soils have a high infiltration rate even v B.The soils have a moderate infiltration rate when thoroughly wetted. C.The soils have a slow infiltration rate when thoroughly wetted. The D.(High runoff potential). The soils have a very slow infiltration rate rate of water transmission.
Open Space	A portion of a cluster development that is set aside for public or private use and is not developed. The space may be used for active or passive recreation, or may be reserved to protect or buffer natural areas (see also Green Space).
Parking Groves	A variation on the hybrid parking lot design, that uses a grid of trees and bollards to delineate parking stalls and create a shady environment. The permeable stalls reduce impervious land coverage while the trees reduce the heat island effect and improve soil permeability.
Perennial Stream	A stream channel that has running water throughout the year.
Percolation	The downward movement of water through soil layers, as contrasted with infiltration which is the entry of water into the surface of the soil.
Permeable	A type of soil or other material that allows passage of water or other liquid.
Permeable Surfaces	Surfaces made up of materials that allow stormwater to infiltrate the underlying soils (e.g., soil covered or vegetated areas).
Pervious	A soil or material that allows the passage of water or other liquid.

Permeable Interlocking Concrete Pavers (PICP)	A concrete block units replicating the appearance of cobblestone that create open voids by beveling the corners of each block and/or wider spacing between the blocks. Use as a type of porous/permeable pavement.
Point Source Pollution	A source of pollutants from a single point of conveyance, such as a pipe. For example, the discharge from a sewage treatment plant or a factory is a point source pollutant.
Pollutants	A chemical or other additive that adversely alters the physical, chemical, or biological properties of the environment.
Porous/Permeable Pavement (PP)	Asphalt or concrete paving material consisting of a coarse mixture cemented together with sufficient interconnected voids to provide a high rate of permeability.
Rainwater Harvesting (RWH)	The principle of collecting and using precipitation from a catchments surface. This can be done by storing rainwater in tanks and cisterns for irrigation, household use, or for drinking water, or can merely be the directing of runoff from impervious surfaces to landscape elements for irrigation.
Receiving Waters	Water bodies such as lakes, rivers, wetlands, bays, and coastal waters that receive runoff.
Recharge Area	A land area in which surface water infiltrates soil and reaches to the zone of saturation, such as where rainwater soaks through the earth to reach an aquifer.
Recharge	Infiltration of surface water to groundwater.
Reinforced Grass Pavement (RGP)	A grass system that is comprised of a sandy gravel Base Course, a plastic support and grid structure, soil mixture, and grass seed or sod.
Reinforced Porous Gravel Pavement (RPGP)	A gravel system that is comprised of a sandy gravel Base Course, a plastic support and grid structure, and a layer of medium aggregate or decorative rock..
Retrofit	To provide or add new equipment, parts, structures, or techniques made available after the time of original construction or manufacture.

Riparian Area	Habitat found along the bank of a natural and freshwater waterway, such as a river, stream, or creek, that provides for a high density, diversity, and productivity of plant and animal species.
Runoff	Water from sources such as rain, melted snow, agricultural or landscape irrigation that flows over the land surface.
Runoff Coefficient	The runoff coefficient measures permeability and determines the portion of rainfall that will run off the watershed. The runoff coefficient value, expressed as 'C', can vary from close to zero to as high as 1.0. A low 'C' value indicates that most of the water is retained for a time at the site, by soaking into the ground or forming puddles, whereas a high 'C' value means that the majority of the rain is runoff.
Runoff Control Volume (ROCV)	The volume of stormwater created from one inch of rain on an impervious surface.
Setback	A required, specified distance between a building or structure and a lot line or lines. A setback can be used as a tool to protect sensitive areas from negative impacts associated with development.
Shared Parking	A strategy designed to reduce the total number of parking spaces needed within an area, by allowing adjacent users to share parking areas during non competing hours of operation (e.g., a shared lot for a theater and an office building).
Sheetflow	A flow condition during a storm where the depth of stormwater runoff is very shallow in depth and spread uniformly over the land surface. A sheet flow can quickly change into a concentrated channel flow within several hundred feet.
Stormwater Conveyance	A system of gutters, pipes, or ditches used to carry stormwater from surrounding land areas to constructed or natural drainage systems.
Stormwater Runoff	Rain that flows over the surface of the land without penetrating the soil.
Structural Control	A practice that involves design and construction of a facility to mitigate the adverse impact of urban runoff and often requires maintenance.

Subdivision	The process (and result) of dividing a parcel of land into smaller buildable sites, streets, open spaces, public areas, and the designation of utilities and other improvements. State and local regulations govern the density and design of new subdivisions.
Surface Water	Water on the surface of the land that has not infiltrated the soil including streams, lakes, rivers, and ponds.
Treatment Control IMP	Any engineered system designed to removed pollutants by a variety of methods such as simple gravity to settle particulate pollutants, filtration, biological uptake, media absorption or any other physical, biological, or chemical process.
Treatment Train	A stormwater technique in which several treatment types (filtration, infiltration, retention, evaporation) are used in conjunction with one another and are integrated into a comprehensive runoff management system.
Vector	Any insect (e.g.: mosquitoes) or other organism that is capable of harboring or transmitting a causative agent of human disease (e.g.: virus, bacterium, fungus, etc.).
Vegetated buffer (VB)	An area of either planted or native vegetation, situated between a potential, pollutant-source area and a wash or surface-water body that receives runoff. Vegetated filter strips are broad sloped open vegetated areas that accept shallow runoff from surrounding areas as distributed sheet flow
Vegetated/Rock Swale (VRS)	A vegetated or rock lined open drainage channel that has been explicitly designed to detain, evaporate, and/or infiltrate the runoff associated with a storm event.
Water Table	The upper surface of groundwater or the level below which the soil is saturated with water. The water table indicates the uppermost extent of ground water.
Watercourse	A permanent or intermittent stream or other body of water, either natural or improved, which gathers or carries surface water.
Watershed	(see Drainage Basin) The geographic region within which water drains into a particular river, stream or body of water. A watershed

includes hills, lowlands, and the body of water into which the land drains. Watershed boundaries are defined by the ridges of separating watersheds.

Zoning A mapped area to which a uniform set of regulations apply. Zoning may govern the use, placement, spacing, and size of land and buildings within a specific area (zone).

APPENDIX B – COUNTY OF SAN DIEGO LID LITERATURE REVIEW

The following Low Impact Development literature review was performed by County of San Diego Department of Planning and Land Use in December 31, 2007. It is presented here to provide current, relevant references on many aspects of LID for the reader.

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